Electrical Engineering

June
1938

Published Monthly by the
American Institute of Electrical Engineers

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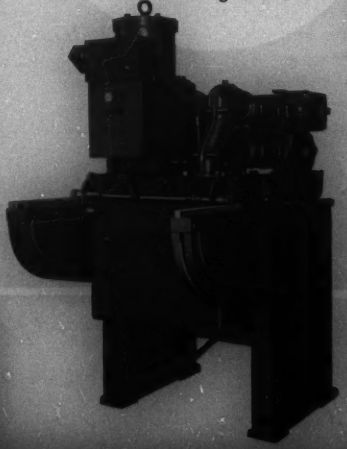

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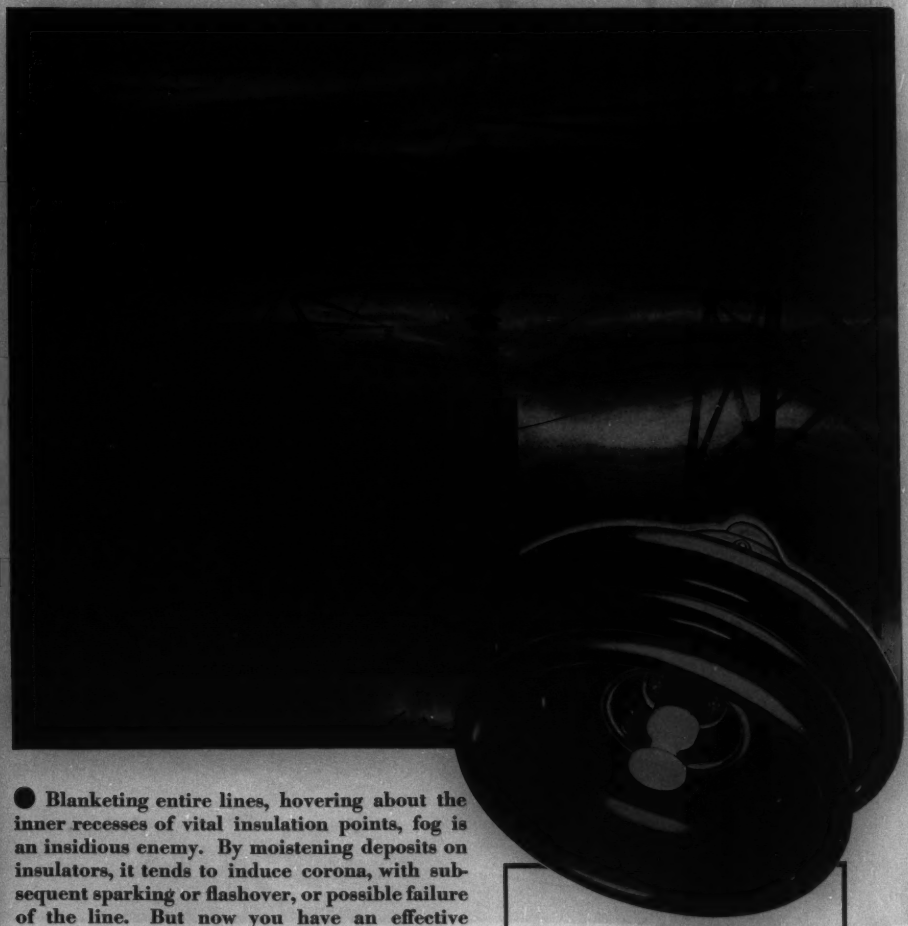

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* Smog: A blend of smoke and fog.—*Webster.*

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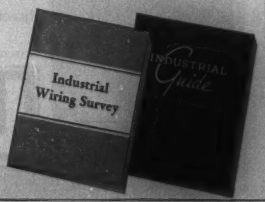

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See Catalog N-33A

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Electrical Engineering

Registered U. S. Patent Office

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The Cover

One of the many scenes that those attending the forthcoming AIEE summer convention in Washington, D. C., may enjoy

Westinghouse Photo

High Lights

Modern Electric Vehicles. A two-session symposium on modern electric passenger vehicles was held during the AIEE 1938 winter convention; three of the eight papers presented are published in this issue. One paper discusses the satisfactory results obtained with new street cars of the President's Conference Committee type in Pittsburgh, Pa. (*Transactions pages 315–17*). A comparison between busses having mechanical drives and gas-electric drives for a transportation system in Philadelphia, Pa., faced with the necessity of replacing much of its equipment, is reported in the second paper; tests showed greater fuel consumption for gas-electric drive, but also higher schedule speed and lower maintenance (*Transactions pages 318–23*). How a transportation company in Chicago, Ill., is attempting to satisfy the demands of its customers for new style, more power, greater comfort, and higher speed is told in the third paper (*Transactions pages 324–7*).

Electronic Speed Control. Two papers in this issue describe methods of using electronic devices for controlling the speed of electric motors. One paper (*Transactions pages 343–52*) outlines three methods of controlling the speed of a motor operating from an a-c power supply. For controlling the speed of d-c motors, the thyratron offers full control and quickness of response (*Transactions pages 335–42*).

Fluorescent Lamps. Heretofore, colored light has been obtained primarily from incandescent lamps by means of some special filtering material, at relatively low efficiency. A recently introduced low-voltage fluorescent lamp is capable of producing colored light, as well as a good imitation of daylight, at efficiencies much greater than those associated with incandescent lighting (*pages 245–8*).

Transmission for Television. If the art of television should follow a path similar to that of radiobroadcasting, some means for connecting stations will be required that can transmit a band width of several megacycles without appreciable distortion. Recent experiments have shown that coaxial cables, developed for telephone use, may be adapted to fulfill the requirements (*pages 249–56*).

Today's Opportunity for the Young Engineer. The young engineer graduating from college today faces a difficult situation. By cultivating a practical point of view toward it, however, he may gain experience at the very outset that will assist him in solving problems likely to recur again and again throughout his entire professional career (*pages 256–8*).

Petersen Coils. Application of a Petersen coil to a transmission line traversing mountainous country and exposed to lightning is reported to have reduced the number of tripouts caused by lightning. The coil was adjusted or tuned with the system in two ways, and staged tests were made of the arcing time at faults (*Transactions pages 295–302*).

Lightning Currents. Study of three-year records of several companies relative to lightning discharge currents through distribution lightning arresters shows that 50 per cent of the currents may be at least as great as 1,300 amperes; circuit rating seems to have no definite effect on discharge currents (*Transactions pages 307–12*).

Summer Convention. Details of the business and technical sessions of the AIEE 1938 summer convention being held June 20–24 in Washington, D. C., have been completed. The program includes ten conference sessions, and the annual business meeting and conference of officers, delegates, and members (*pages 259–61*).

Electricity in Medicine. Electricity in the practice of medicine may be either an esoteric instrument of the quack or a useful tool in the hands of a competent physician. Many of the legitimate electromedical devices, which are based upon sound scientific principles, may be interesting to electrical engineers (*pages 237–44*).

Thyratron Lighting Control. Among the many control applications of the thyratron tube is the control of lighting intensity, particularly in theaters. Some of the new equipment, new systems, and new theatrical practices made possible by the use of the thyratron are described in this issue (*Transactions pages 328–34*).

Pacific Coast Convention. Arrangements for the AIEE 1938 Pacific Coast convention are nearing completion. The dates, August 9–12, are particularly attractive to those wishing to make combined vacation-convention trips (*pages 260–1*).

Section and Branch Activities. During the year ending April 30, 1938, 624 meetings of AIEE Sections and 1,334 meetings of Student Branches were held; three new Sections and one new Branch were organized (*pages 263–6*).

Coming Soon. Among articles and papers now undergoing preparation for publication in early issues, are the following: an article on the role of the library in engineering education and research, by H. W. Craver; an article discussing the engineer and his relation to current trends in economic thought, both in the United States and in other countries, by Past President F. B. Jewett; an article presenting a graphical method of multiplying and dividing complex quantities, by E. C. Goodale (A'27); an article philosophically discussing our scientific era from the historical point of view, by Alfred Still (F'14); a paper describing a high-speed circuit breaker for railway use, by W. F. Skeats (M'36); a motion-picture study of traveling waves on transmission lines, by L. F. Woodruff (M'33); a paper presenting the results of a calculating-board study of the recovery-voltage characteristics of transmission systems, by R. D. Evans (M'26) and A. C. Monteith (A'25); and a paper describing a stabilized vacuum-tube amplifier devised for use in the measurement and instrument system of an a-c network analyzer, by H. A. Thompson (A'37).

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DISCUSSIONS

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A System of Electric Remote-Control Accounting—Woodruff 357

Transportation

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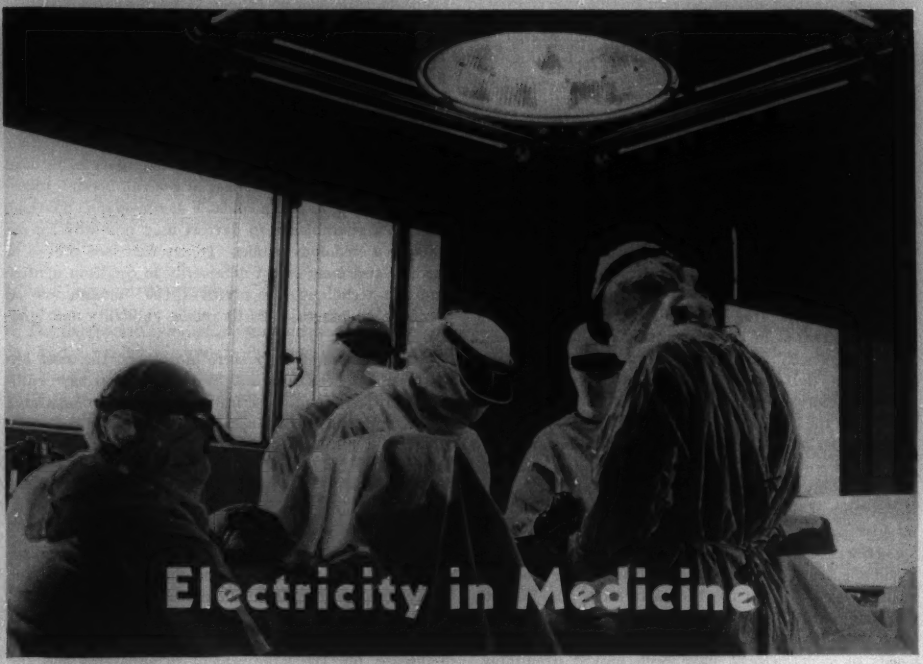

Electricity in Medicine

As long ago as 1882 D'Arsonval predicted that electricity would be used widely in the treatment of disease. Today that prediction has been fulfilled—indeed, exceeded—because electricity now plays a highly important part not only in the treatment of disease but also in its detection and diagnosis. A few of the manifold electromedical applications are described here.

By R. E. WILLIAMS
ASSOCIATE AIEE

PROBABLY medicine as a profession antedates all other scientific professions of which there is any record. Instinctive in man is the urge to administer aid to a fallen comrade, or to secure relief from illness or plague. Egyptologists and Orientalists have reported definite historical evidence of the practice of medicine in ancient Egypt, China, and other oriental nations, but imagination need not be overtaxed to recognize a crude attempt at the practice of medicine among even the remotest of prehistoric races. Indeed, wherever the light of knowledge and education has not managed to infiltrate the gloom of centuries, remnants of primeval races still tolerate the tom-tom-beating medicine man, the conjurer, and the herb doctor.

Many centuries later the medical practitioner began to look to science—basic chemistry and physics—for assistance in his attack upon the vagaries and superstitions surrounding the theories of human maladies. In the meantime electricity, in contradistinction to medicine, had had its beginnings as a science; yet for more than 1,000 years, through the Dark Ages and even beyond the Renaissance in Europe, the theories of electricity, like medicine, were so shrouded in occultism, charlatanry, and alchemy that probably not until 1748 did the science of electricity find a definite identification with the profession of medicine. In that year, according to de La Rive,[1] the therapeutic applications of electricity were first entertained by Jallabert (or Jalabert), who submitted invalids to electrical treatment by drawing sparks from their bodies. He thought he discovered that electrization stimulated the circulation of blood, that it was capable of awakening dormant sensation or restoring to usefulness a paralyzed organ, and that it produced involuntary convulsive movements. He is said to have ameliorated by the applications of electricity the inconvenience of a man whose arm was paralyzed. A detailed account of this experiment by Jallabert was read by Teske[2] before the Royal Society in London in 1759.

Galvani[3] contemporaneously carried on important investigations in physiological electricity, but his interests were mostly hypothetical, and the application of his discoveries

R. E. WILLIAMS is a member of the Institute's publication staff. The author acknowledges the assistance of Doctor J. M. Carlisle, Westfield, N. J., and the generous co-operation of Doctor H. A. Carter, secretary of the council on physical therapy, American Medical Association.

1. For all numbered references, see list at end of article.

was left to Humboldt, Aldini (Galvani's nephew and pupil), and others. Galvani first demonstrated the existence of animal electricity by means of a frog. He made an electrical connection between the nerves and muscles of a frog and observed an electric current in the connecting link; but unfortunately the interconnection was bimetallic, and Volta contested Galvani's findings on the premise that the current was produced by a thermocouple action instead of an internal generation of electricity. Galvani then used a homogeneous metal to connect the muscles and nerves of the frog, and obtained similar results; whereupon a long discussion was precipitated between the two men and their respective partisans, concerning the cause of the muscular contractions experienced by the frog during the original experiment. Galvani persisted in the assumption of the existence of animal electricity; Volta sought with equal tenacity to prove that the current could be produced by contact potentials between any two dissimilar substances, however slight the dissimilarity might be.

Both sides of the argument, which grew bitter toward the end, were conducted with almost equal ingenuity, but eventually the ideas of Volta gained credence among the savants of the day and predominated over the logic of his adversary.

Such were the beginnings of contiguity between the two broad sciences of electricity and medicine. The road they have traveled together has been a tortuous one, for with propriety entirely becoming the profession, physicians have been reluctant to accept new methods until the merits of such methods have been proved irrefutably. The use of electricity in medicine has been somewhat handicapped moreover by a lack of general understanding of its nature, and physicians have been concerned necessarily with the possible adverse psychological effects produced in patients by the use of electrical devices in either the diagnosis or treatment of diseases.

Today the barriers of antipathy and misunderstanding are being set aside, and electricity is becoming a valuable ally of the physician in his never-ending crusade against the maladies that beset the human body. Electricity is proving its merit. Medical practitioners and investigators have not often acepted strange, untried electromedical equipment with open arms; they have rejected it time after time, forced designers to improve it, and have used it only after it has been found to offer concrete practical advantages over more conventional equipment. Electrical devices probably never will revolutionize the science of medicine, but there are many interesting and successful applications of electricity in medicine, and a few of the more important ones are described in the following paragraphs.

Electricity in Diagnosis

Dozens of different kinds of electrodiagnostic contrivances have been manufactured, sold, used; and many have been cast aside during the last 25 years. Some of them have been worthless but harmless; others have been instruments of quackery; a few have survived all the scientific and ethical demands of the medical profession, and are in general use today. Occasionally irresponsible manufacturers have attempted to project worthless "gadgets" into medical science, or to circumvent legitimate medical practitioners by selling expensive, useless, perhaps harmful, spurious electromedical apparatus to the public. Such practices have been definite deterrents to medical acceptance of electrical devices in general, because physicians have maintained a laudable aloofness from anything bearing a resemblance to devices used primarily for exploiting a credulous public. To say that fads prevail in medical treatment is not necessarily to condemn modern curative technique, for much of the "modishness" is forced upon practitioners by public gullibility and ignorance.

Although undoubtedly there are others, the most important of the electrical aids to diagnosis that have withstood critical scientific scrutiny and have demonstrated their own merit over a long period of time are (1) X rays, (2) the electrocardiograph, and (3) the incandescent lamp.

Radiography in Diagnosis

No lengthy exposition of the use of X rays as a diagnostic medium is necessary, for the importance of the X-ray department in the modern hospital and its function in diagnosis are fairly generally understood. X-ray equipment is indispensable in both the diagnosis and treatment of disease, but the improvement in apparatus and the technique of its use has been so rapid that few general practitioners find it profitable to keep either their knowledge or equipment fully up to date. As a result, X-ray technicians have begun to establish a specialized field in medicine. About one-fourth of all practicing physicians in the United States own some X-ray equipment, but there are more than 1,000 that devote their entire time to X-ray research and treatment.

The X rays of most interest, and most useful to medical science, are those with wave lengths of from 0.1 to 1 angstrom unit, although both longer and shorter waves have been produced, and probably may be found useful.[4] Several hospitals in the United States now are using X rays produced at 1,000,000 volts or more, but such "hard" radiations have found little use in diagnosis.

The layman is familiar with radiographs of bony structures for the detection of fractures or malformations, but this is only a beginning of the nicely refined technique of radiography. Bones, teeth, foreign bodies, and any dense or calcareous parts immediately are thrown into shadow relief upon application of the radiations. This is simple—but a whole science has evolved from the attempt to outline some of the soft tissues and organs of the body. By administering either orally or by injection a suspension of barium sulphate, which is highly opaque to X rays but is not absorbed by the body, the alimentary canal may be examined. The precipitate of barium salt lines the canal and therefore outlines the tract on the X-ray film. Other soft organs may be "isolated" for purposes of X-ray

diagnosis by injections of iodized oil and other chemical substances that are concentrated specifically in the organ under observation.

Diagnosis of conditions in pregnancy is a relatively new application of radiography. Frowned upon at first by superstitious or apprehensive patients and conservative physicians, it is believed now to be perfectly safe in the hands of a competent roentgenologist. It is particularly useful in detecting multiple pregnancy and malformations in either the patient or the fetus, so that the obstetrician may take suitable precautions early enough to avoid complications in delivery.

The Electrocardiograph

The electrocardiograph is an instrument used for detecting and recording the minute electrical variations within the heart. According to existing physiological concepts, activity in all living tissue is associated with an electrical change. The active part of the tissue acquires a negative potential with respect to the inactive part, and a current will tend to flow through an external circuit from the inactive part to the active, if suitable electrodes are applied. Incidentally, Galvani enunciated the essence of this theory during his work on electrophysiology already mentioned. Activity in muscle is associated with surprisingly large changes of potential—20 millivolts or more—and in the heart, which fundamentally is no more than a mass of specialized muscular tissue arranged so that the organ functions as a pump, the activity is rhythmic. Accordingly, there is a corresponding rhythmic, periodic wave of potential difference between any two points on the surface of the heart.

The tissues surrounding the heart are fairly good conductors of electricity; consequently, much of the potential difference between the two points on the heart's surface disappears. If electrodes are applied to the hands or arms, the rhythmic differences of potential corresponding to the activity of the heart may be detected, however, and usually have crest values of one millivolt or more.

That the action of the heart is accompanied by electrical changes has been known since 1856, when Kölliker and Muller demonstrated by physiological experiment that the beat of the isolated heart of a frog was accompanied by electrical changes. Waller, an English physiologist, demonstrated in 1887 that the heart current could be made to pass through a galvanometer and cause it to deflect, but little significance was attached to the discovery at that time.

In 1903 Einthoven designed a string galvanometer of sufficient delicacy to respond to the rapidly varying electrical changes from the heart, and following the publication of his clinical studies several years later, the clinical use of the electrocardiograph became more widespread until today it is an important adjunct in not only the diagnosis but also the prognosis of heart conditions and diseases. Much of Einthoven's technique is still used as standard clinical practice today, principally because his work was thorough and rational, and because some sort of standardized practice is necessary in order that the work of various cardiologists may be directly comparable. The three standard connections to the patient, or "leads," used universally just as Einthoven prescribed them, are made in such a way that the first record delineates the voltages across the base of the heart; the second shows voltages between the base and apex of the heart; and the third describes electrical changes chiefly in the left ventricle.

Superficially, there are three kinds of electrocardiographs: (1) the string-galvanometer type; (2) the amplifier type; and (3) the cathode-ray type.

The string-galvanometer electrocardiograph, which essentially is only a variety of recording galvanometer, has been used in hospitals and special clinics for several years, and has given reasonably accurate, dependable results; nevertheless, it has many unsatisfactory characteristics that likely will cause it to be displaced eventually by the other types of equipment, which are more convenient. The other two kinds of electrocardiographs are fundamentally similar to the vibrator and cathode-ray oscillographs used in electrical engineering, the only notable departure being in sensitivity. For example, Reid and Caldwell,[8] in studying special problems have used an amplifier electrocardiograph of such high sensitivity that strips of sensitized paper five inches wide are necessary to record the high amplitudes of the amplified heart waves.

Details of electrocardiographic circuits and operating technique are interesting, perhaps in themselves worthy of separate description. But an exposition so extensive cannot be told in a few words; besides, there is little point in reiterating a story already well told elsewhere.[5–10] For those interested in the significance and interpretation of electrocardiograms the descriptive works of Wiggers[7] and Wilson[11] are recommended.

The Incandescent Lamp in Diagnosis

Physicians have found no new or startling uses for incandescent lamps, which have the same use in medical diagnosis as in every man's home—to supply light in dark places. In examining the passages of the respiratory and digestive systems the incandescent lamp is to be found in daily use in any well-regulated clinic. The forms of the lamps may be as unfamiliar as the names of the technique for which they are used, but the actual use seldom departs from this fundamental purpose of lighting dark cavities of the body. In rare instances incandescent lamps are used for controlled local heating.

Aside from the unusual shapes and sizes of the envelopes, medical incandescent lamps are not much different from the prosaic article now purchasable for a few cents at the corner drug store.

Relation of Body Impedance to Disease

Many investigators have attempted to explain the action of a human body included in an electric circuit. Its electrical characteristics have been described by means of equivalent circuits, and determined quantitatively by measurement; yet no correlation between disease and electrical characteristics of the body has been rationalized

sufficiently to become generally valuable in diagnosis. As long ago as 1888 Vigouroux observed that ostensibly the d-c resistance of the human body changes during diseases of the thyroid gland, but later experiments[30] failed to corroborate that hypothesis. Strangely, although failing to confirm Vigouroux's correlation of d-c resistance and irregularities of the thyroid gland, Brazier, among others, has found a rather definite relationship between body impedance (or really what he termed "impedance angle," the ratio of reactance to impedance) and the basal metabolic rate.

Since the determination of the basal metabolic rate is a routine aid to the diagnosis of thyrotoxicosis, the measurement of body power factor logically could be applied as a diagnostic test for diseases of the thyroid gland. The basal metabolic rate is a measure of the energy output or heat production of an individual in state of complete mental and physical rest. It is measured as the calorie output per square meter per unit of time, and is subject to enormous errors; therefore, the method of diagnosis by means of alternating current may become highly significant in clinical practice. At present the method still is a research implement. It has been used experimentally in England, and at Harvard University and The Johns Hopkins University in the United States.

Electricity in Therapy and Surgery

Possibly because of much publicity, the layman is more aware of the glamorous part played by electricity in the cure of disease than of the equally important processes of electrodiagnosis. For example, most people have been informed that X rays are being employed, perhaps with some small degree of success, to wage war against that dread foe of mankind known as cancer, for only through widespread public education can the medical profession hope to combat such an insidious malady. It is cured with least difficulty if detected in the simple unobtrusive forms in which it frequently first manifests itself. This is a legitimate use of medical publicity, yet not all electromedical processes have been publicized so worthily. Many formidable-looking machines without any scientific justification, but apparently with much psychological and "box office" appeal, have been used for years by quacks and charlatans, the modern versions of the medieval mystics. One of these electrical gadgets supposedly was based upon a theory that every disease causes the body to radiate electrical energy at some specific frequency peculiar to that disease. The same machine diagnosed and likewise treated all diseases, each malady having its own colored light on the front of an impressive control panel. As the specific frequency of the patient was discovered, the proper colored lamp flashed, thus "informing" the operator of an actually predetermined treatment. The treatment, the same for tonsilitis or gall stones, consisted of some sort of electric shock that never failed to *impress* the patient; and sometimes it effected a complete cure—at least psychologically. Most ethical physicians merely looked askance at this remarkable machine, but a few crusaders succeeded in making it look so ridiculous that it retired from the scene hastily and confusedly. The name of this miracle machine is known to most physicians, and many volumes could be written about equally famous, or infamous, devices employed by pseudomedical cults of the present and the past; however, that is a separate chapter in medical history and is of no interest here, except to show why many conservative medical practitioners are inclined to be skeptical of unproved electromedical equipment, and why the actual development and application of electromedical equipment proceeds so slowly.

The legitimate and accepted division of medical treatment known as physical therapy may be divided into five main branches:

1. Light therapy, the treatment of disease by means of "light" rays.
2. Heat therapy, employing various types of heating devices.
3. Electrotherapy, using electricity.
4. Hydrotherapy, the employment of various water applications.
5. Mechanotherapy, treatment by massage, corrective exercises, and mechanical devices.

Light therapy includes treatment by ultraviolet and infrared radiations; heat therapy includes stimulation of artificial fever by means of high-frequency radio emissions; electrotherapy, in its restricted medical sense, is the treatment of disease by means of electric or diathermy current used to produce deep local or general heating effects. Hydrotherapy is commonplace: As a stimulant, cold water is dashed into the face of a fainting person; as a sedative, a bath at 100 degrees Fahrenheit is prescribed; as an invigorator the cold shower is well known.

Obviously electricity is indispensable in light therapy, heat therapy, and electrotherapy, and may be important in the other branches of physical therapy. But this is only a beginning of the therapeutic applications of electricity. Most important of the other uses are: radiotherapy, the treatment of disease by means of radium and X rays; and electrosurgery, which of course is a corrective technique being considered arbitrarily among the therapeutic applications.

Light Therapy

"Light therapy may be defined as the treatment of diseases by means of light rays (particularly invisible light rays)."[12] The definition of light therapy given by the council on physical therapy of the American Medical Association is: "a limited term used by some physicians to designate the therapeutic application of radiation in the visible spectrum: some include also ultraviolet radiation." Although this latter definition is more precise scientifically, it is not correct practically, because in general the term "light therapy" is used rather loosely in discussing all types of radiation; that is, ultraviolet, visible, and infrared.

As radiant energy is absorbed by the tissue cells it produces a complex variety of physical, chemical, and biological reactions. From the standpoint of physical therapy, radiant energy is classified as either photothermal

or photochemical radiation.[13] Photothermal radiations, comprising infrared and visible radiations, penetrate subcutaneous tissues, heat the blood, accelerate vital reactions, act instantaneously; they produce a burning sensation or immediate burn, if their intensity is too great.

Photochemical radiation, or ultraviolet radiation, penetrates the skin only to a depth of a fraction of a millimeter; it is absorbed by protoplasm, and this absorption causes physical and biological changes that manifest themselves only several hours after exposure. Thermal radiations are employed usually for immediate local action, but photochemical radiations are used for their subsequent effect on the general organism.

The medical profession is divided in opinion regarding the therapeutic expediency of these radiations. Some contend that ultraviolet applications are useful only as a substitute for heliotherapy (treatment of disease by exposure to the sun's rays); nevertheless, in many instances the use of artificial ultraviolet generators ordinarily is more convenient than heliotherapy, and a desired dosage may be administered more quickly and accurately. Furthermore, specific wave bands may be filtered from the output of the clinical ultraviolet generator for special long- or short-wave radiations, although there is little clinical evidence that the effect of the short-wave ultraviolet radiations physiologically is any different from the effect of the long-wave ultraviolet, except that the long waves have slightly greater penetrating power.

Ultraviolet radiations applied locally may be useful in their bactericidal action. Almost all bacteria may be killed by sunlight or the radiant energy emitted by artificial sources, but there is much variation in the rapidity with which they are destroyed. A bactericidal action is exerted by all radiations having wave lengths between 3,000 and 2,500 angstrom units, although there is a definite characteristic curve of bactericidal effectiveness for different bacteria; for instance, emissions at 2,650 angstrom units are said to be most effective for colon bacilli.

As radiant energy at wave lengths shorter than 4,500 angstrom units does not penetrate the skin, destruction of germs in the deep sections of the skin is impossible, and the direct bactericidal action of ultraviolet is most useful in treating infections located on the surface of the body.

Infrared radiation should not be assumed to have any extraordinary therapeutic effect. It is merely a convenient method of localized heating of some part of the body. Both luminous and nonluminous heat radiations produce marked hyperemia (abnormal localized accumulation of blood), tissue relaxation, and relief of pain in the irradiated area. These effects assist in the resorption of products of wounds and inflammatory reaction and aid the natural forces of defense and restoration.

The advantages of infrared irradiation over the more conventional method of conductive heating are that its action is effective to a much greater depth; there is no pressure over the parts treated; and the parts may be kept under continuous observation, so that signs of excessive heating may be discovered at once. In all sources of ultraviolet radiation the proportion and intensity of the various wave lengths varies widely; moreover, variations in styles of reflectors, applicators, current, voltage, and distance between electrodes affect the intensity of the radiations, so that different radiations may be obtained from the same source merely by changing the controlling conditions. Because of these variables, the council on physical therapy of the American Medical Association has established a standard, based upon the erythemal (broadly, "sunburning") effect, for judging the effectiveness of ultraviolet sources. Since the emission line of the mercury-arc lamp at 2,967 angstrom units has the greatest erythemal effect, this line has been selected as the standard of evaluating all other sources, and an energy concentration of 20 microwatts per square centimeter at a distance of two feet from the front edge of the reflector, at this standard wave length, is known as the erythemal unit (E.U.) of dosage.

Readers interested in the apparatus used for light therapy should consult an article by Laurens,[14] who has written definitively concerning the various types of radiant-energy sources, including a résumé of the factors involved in the selection of the proper variety for a specific application, and Coblentz[15] has described the physical characteristics of the radiators in a manner far more adequate than is possible here.

X-Ray Therapy

Each variety of cell in the body is specifically sensitive to roentgen rays or the radiations emanating from radium. Certain cells are extremely sensitive and are destroyed or injured by small doses; other varieties are resistant and can tolerate relatively large doses with apparent impunity.[16] On this simple premise hinges a field of therapeutic treatment scarcely touched by medical research, and probably little understood. On the basis of many experiments, radiologists have determined that the radiosensitiveness of cells depends largely upon their rate of metabolism; in other words, upon the natural life cycle of the cells. Logically, an abnormal cell probably does not have the same life cycle as a normal or healthy one, so that by careful selection of frequencies and dosages, the roentgenologist can concentrate upon unhealthy cells and deter or destroy their growth with only small detriment to surrounding tissues, because of their differences in sensitiveness.

The absorption of the rays in the human body is governed by definite physical laws, and the proper use of X rays for therapy requires exact knowledge of the quality, or wave-length distribution of the rays, and of the quantity or dose. If the proper wave length is known, the voltage to be applied to the tube may be computed approximately from the equation of Duane and Hunt[17]

$$V = \frac{12.35}{\lambda}$$

in which V is the potential difference in kilovolts and λ is the wave length in angstrom units.

Skin diseases ordinarily are treated with "soft" rays,

or so-called "grenz" rays, because only the long-wave rays are absorbed by the skin. Short-wave rays pass through the skin with little effect, but to treat an internal tumor such radiations are necessary. If the generation of X rays with only a single wave length under given conditions were possible, the entire technique of X-ray therapy would be greatly simplified, but the radiations generated in an X-ray tube are heterogeneous and contain various wave lengths, each with a different absorbability in the body and a different therapeutic effect. Nevertheless, the heterogeneous beam has an "effective" wave length that is characteristic of the radiations always generated under the same conditions. In order to screen out the softer rays, better to control the known characteristics of the beam and make it more homogeneous, metallic filters sometimes are used.

Exposure to X rays may be followed by loss of appetite, nausea, and vomiting. The intensity of such reaction depends upon the part of the body exposed, the area of the surface, and upon the ease with which the digestive equilibrium of the patient may be disturbed. Prolonged or continual exposure to the radiations may cause sterility, annoying, painful burns that heal slowly, and other disorders. Consequently, the dosage of X rays must be controlled accurately to obtain the desired result; in 1928 an international unit of dosage, the roentgen unit or *r*, based upon the ionizing power of the rays upon air, was adopted by roentgenologists. Treatments therefore are specified in so many *r* units per minute.

About 1920 radiotherapy entered a new phase, and has continued to expand in the manner then adopted. Previous experience had shown that in the treatment of resistant tumorous growths, especially those residing in the deep portions of the chest or abdomen, the rays available at that time were not particularly effective. This was thought to be attributable to the inability of the rays to penetrate the body sufficiently to reach the malignant growths; therefore, a clamor for more penetrating rays arose among the roentgenologists, and tube designers and manufacturers of X-ray equipment proceeded to satisfy the demand by producing apparatus operating at voltages of from 200,000 to 300,000. Such generators enabled the therapeutic radiologist to deliver to deeper parts of the body a much larger dosage of the rays, and as a result certain tumors, previously not responsive to radiology, became somewhat more corrigible.

In spite of these improvements, certain tumors were not influenced by any variation, and this led to a demand for still more penetrating rays. Another reason for the demand is that the high cost of radium prevented many institutions and private practitioners from using that element for external radiation at a distance. Only a few institutions in the world have a sufficient quantity of radium to employ it in this way; as a result, since 1930 several X-ray machines capable of operating at from 500 to 1,000 kilovolts have been constructed. Radiations generated at such high voltages are extremely penetrating and, although they do not correspond exactly to the gamma radiations of radium, they produce a somewhat similar result. One of the largest machines of this type is used by the Institute of Cancer Research of Columbia University almost exclusively in irradiating cancerous growths, and is situated in the Presbyterian Hospital in New York City. Apparatus operating at comparable voltages is in operation at the Huntington Memorial Hospital of the Harvard Medical School at Boston, Mass.

Although such high-voltage equipment is desirable and advantageous, it cannot replace radium or therapeutic apparatus of lower voltage because each has a definite specific use and value in medicine, and is indispensable. It is still in the experimental period of development, has only highly specialized applications at present, but possibly may become a potent weapon in the war against cancer.

Electrotherapy

As Jallabert found, the conduction of current through the body effects some profound reactions, which may be beneficial in the treatment of disease. Jallabert probably did not know why electric currents mitigated the suffering in the bodies of his patients, but today the physiological

Photo courtesy Doctor Francis Carter Wood

This $30,000 therapeutic X-ray generator, which is operated experimentally by the Institute of Cancer Research of Columbia University in New York City, is capable of producing radiations at 1,250 kv, but normally operates at 900 or 1,000 kv. Radiations are projected through lead-covered stainless-steel tubes, which may be seen at the right in the photograph, and may be aimed accurately at cancerous growths. Four patients may be treated simultaneously

and therapeutic actions of electricity are known precisely to be attributable to chemical and physical changes that it produces in the tissues.

For some years high-frequency currents were used empirically in medicine, without much knowledge of the reasons for their therapeutic effects, but the physiological and therapeutic results now are believed to be entirely dependent upon the generation of heat within the tissues. Just as some electrical energy is consumed in overcoming the resistance of ordinary conductors, so the body tissues consume energy, and the temperature rise may be many degrees above normal. The heat generated by high-frequency current is distributed along the path traversed, so that the deep tissues may be heated as well as the superficial tissues, and for this reason such currents are called "diathermy" currents.

Methods of Treatment by Diathermy

So manifold and complex are the uses of diathermy and closely related practices that volumes could be, and have been, written on this subject alone. Arbitrarily the whole field of diathermy may be divided into four parts: (1) general diathermy, (2) autocondensation, (3) hyperpyrexia by diathermy, and (4) electrosurgery. The fourth may not be, by definition, a class of diathermy treatment, but is closely related to the others so far as the physical characteristics of the process are concerned, and is most conveniently considered with the others.

General diathermy denotes the use of high-frequency current for general heating effects on the body, by the employment of a large electrode surface in direct contact with the skin. Autocondensation is a modification of this method, in which a dielectric is interposed between one electrode and the skin; in other words, the body is made a part of a capacitor. Both methods have been used for years, principally for their mild stimulating effect on body metabolism, although autocondensation was popular at one time for the treatment of high blood pressure. The slight rise in body temperature caused by their use was at first considered to be incidental, and the therapeutic effects of the treatments were attributed to specific influences of the high-frequency currents rather than to the elevation of body temperature.

As a result of more recent investigations in fever production (hyperpyrexia), however, the beneficial effects of the treatments have been acknowledged to be produced by the heating, and diathermy apparatus of larger capacity has been produced for the specialized technique of fever induction. Moreover, the generation of therapeutic fever in a capacitive field by means of high-frequency radiations in the radio spectrum has created a need for apparatus still more powerful, and to operate at still higher frequencies.

General Diathermy. The object of general diathermy is to pass through large electrodes connected to the body a diathermy current of sufficient density to influence general blood circulation and body metabolism. As practiced with apparatus supplying only a small power output, this method produces a temperature rise of only one or two degrees Fahrenheit above normal. With the patient connected to an average diathermy machine by means of large electrodes covering perhaps 100 square inches of skin surface, the diathermy current through the electrodes may be as much as three amperes. After half an hour of such treatment the body temperature usually does not exceed 100 degrees Fahrenheit.

Autocondensation. The physical effect of an autocondensation treatment is to produce local heating of the parts of the body to which the electrodes are connected, as well as to produce general heating of the body as in general diathermy. Ordinarily one or two metal cylinders or plates are applied by direct contact to the palms of the hands, forearms, soles of the feet, or chest, and connected to one output terminal of the diathermy apparatus. A very large electrode, separated from the body by an interposing pad of insulating material, is connected to the other terminal, thus making the patient a part of a capacitor in an oscillatory high-frequency circuit.

The current dosage normally varies from 0.5 to 1.25 amperes applied for 10 or 15 minutes. In the early days of high-frequency therapy a method of autoconduction was practiced, and still is used by some clinicians in Europe. A variant of autocondensation, it consisted of placing the patient inside a solenoid and electromagnetically inducing the high-frequency current in his body.

Hyperpyrexia by Diathermy. Fever production is said to aid the defense and protective mechanisms of the body in some chronic diseases, and is especially helpful in the treatment of gonorrhea, both acute and chronic, because the bacillus of that disease is easily killed by slight increases in temperature. In the treatment of syphilis of the spinal cord there is a race for supremacy between the electrical methods of fever production and the injection of the malaria organism, both of which are capable of producing high fever. Both methods have given favorable results, but neither is sure to bring about any permanent benefit. Electrically induced fever as a curative measure has not received universal approval among medical men, and many prefer to accomplish a similar result by the mere application of heat in an oven; at any rate, further careful study and much practical experience in fever therapy seem to be needed before the best method and the scope of artificial fever production may be determined conclusively. The advantages of electrical fever induction over most of the other methods are said to be the accuracy with which the reaction of the patient may be observed and controlled; the constant availability of the therapeutic agency; and sterility, because the procedure does not introduce toxic substances.

To bring about hyperpyrexia by diathermy the current must be sufficient to produce more heat than is lost by radiation, and some suitable means of insulation is provided to keep the radiation losses as low as possible. At a frequency of 1,000 kilocycles per second the ordinary electrode current requirement is about four or five amperes, which will produce temperatures up to about 107 degrees Fahrenheit without harm.

A few years ago a new method of artificial fever induction was discovered accidentally when persons working near a powerful high-frequency radio transmitter became

overheated and complained of headaches. The overheating was found to be caused by the high-frequency radiations of the transmitter. A special apparatus for producing the same effect, later described by Whitney,[19] was called the "radiotherm," and the method of hyperpyrexia by high-frequency radio waves became known as radiothermy.

Electrosurgery. Any person who has allowed any part of his body to touch a conductor carrying radio-frequency current in a high-voltage circuit needs no description of the theory of electrosurgery, for by practical experience he became acquainted with an excellent potential electrosurgical instrument.

The principal action of all electrosurgical methods is an intense concentration of current under a small active electrode, resulting in a destructive heating effect that leads to instantaneous coagulation of the albumin of the tissues. The extent and form of destruction varies with the type of current and the method of application. In electrocautery—the employment of metal tips or wires heated by ordinary lighting current—the destruction of tissues is superficial and impermanent, and the metal tips cannot be kept at a uniform temperature. The modern high-frequency electrosurgical operating instrument is merely a scalpel or needle connected to a single (ungrounded) terminal of a high-frequency oscillator circuit. Although the instrument remains cool throughout the surgical procedure, a searing heat is developed in the tissues themselves, and is under perfect control of the operator. Electrosurgery, offering complete sterilization of all tissues through which the instrument passes, as well as a remarkable reduction in capillary hemorrhage, has come to fill a definite role in both major and minor surgery, and has made possible some important advances in general surgical technique. In particular the practice of brain surgery has been given an important impetus by the use of electrosurgical devices. Ordinarily, excessive bleeding and the consequent possibility of postoperative shock make brain surgery a hazardous undertaking strictly within the province of a very few specialists. Possibly through the use of electrosurgery, brain operations may come to be regarded with less apprehension in a few years.

Electrical Induction of Medicines

Recently some medical investigators have used direct current for the conduction of certain powerful pharmacologic agents through the skin. A few physicians are enthusiastic about the method, claiming that it is superior to the conventional subcutaneous injection of drugs and to other common methods of inducing medicines through the skin (such as massage). Some localization of medication has been claimed to be possible by this method, but it is not generally acknowledged.

Strictly scientific evaluations have not been ventured by medical authorities, because the experimental work thus far has not been sufficiently comprehensive, but the introduction of drugs into the body electrically has been criticized as lacking adequate control.

The Need for Co-operation Between Physicians and Electrical Engineers

Although the foregoing exposition is cursory and necessarily limited, it is intended to provide some indication of the enormous scope of electrical applications possible in medical science. To treat the subject adequately would require many volumes written by one familiar with electrical engineering, theoretical physics, and medicine. Even a casual survey of the literature available on the subject shows that but few physicians have any great familiarity with the physics of electrical apparatus, and perhaps fewer engineers have any conception of the physiological significance of the processes served by the machines they create. The sciences of both electricity and medicine are still immature, but the rapid advances they have made in combination suggest that more concerted effort might result in a new hope for the annihilation of human disease.

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Low-Voltage Fluorescent Lamps

By G. E. INMAN R. N. THAYER

Colored light usually is obtainable from incandescent lamps only by means of some special filtering material, at relatively low efficiency. Now a new type of lamp, which is tubular in shape and contains a powder that becomes fluorescent in the presence of ultraviolet radiation, produces white light similar in character to daylight, as well as monochromatic light, at efficiencies much larger than those ordinarily associated with incandescent lamps.

FLUORESCENT lamps, that are simple in form and operate through suitable ballast from 115- and 230-volt a-c circuits are among the more important recent advances in lamp design. The lamps are tubular in form, and the fluorescent material is energized by a hot-cathode positive-column electric discharge. Just as a transformer converts one voltage to another, so the fluorescent powder adhering to the inner walls of the envelope converts the invisible ultraviolet radiation in a low-pressure mercury discharge into visible radiation, or light. Progress in the development of these lamps has resulted from a gradual increase in knowledge pertaining to hot cathodes, to the production of short-wave ultraviolet radiation, and to the manufacture of efficient fluorescent powders. The resulting lamp produces colored light many times more efficiently than do present light sources. In addition, fluorescence provides a means of producing for the first time a practical source of white light matching daylight in appearance, efficiently and with low power inputs. Much concentrated effort has been spent in obtaining the desired electrical characteristics of the lamp and on the design of efficient ballast equipment. The lamps described here are in one of several classes of lamps now being developed.

General Characteristics of the Lamp

To obtain the positive-column type of discharge found most efficient for this lamp, the length of the tube should be several times its diameter. One electrode, which serves alternately as cathode and anode, is sealed into each end of the tube. The electrodes are small coils of tungsten wire coated with some material such as barium and strontium carbonates to improve their emissivity. During manufacture these carbonates are changed into oxides. The tungsten wire is small, so that it may be heated sufficiently by the energy of the discharge to provide good emission, and also to heat quickly when the lamp is started. Usually only one or two turns of the tungsten coils are heated to incandescence by the discharge, but the hot spots shift from one section to another during the life of the lamp.

The inner wall of the tube is coated with a thin layer of fluorescent material (also called the phosphor). Inside coating, besides its usual advantages, is essential because the ultraviolet radiation that energizes the phosphor will not pass through ordinary glass. The coating must have sufficient thickness to absorb the impinging ultraviolet radiation, yet must be so thin that it will not absorb too much of its own light or of the light internally directed from the opposite side of the tube. The evolution of a process for obtaining smooth, uniform coatings and lamps of uniform color and efficiency has required much painstaking effort.

The assembled lamp, consisting only of this coated tube and the sealed-in electrode at each end, is evacuated, and the carbonates on the electrodes are decomposed as in radio tube manufacture. A little argon (to facilitate starting) and a small drop of mercury are admitted to the tube and remain without cleanup for the life of the lamp. The resulting structure is simple yet sturdy, as shown in figure 1. Since there is no filament or supporting structure of any kind between the electrodes, the lamp is more rugged than filament lamps of the same size and shape, and withstands far more shock and vibration.

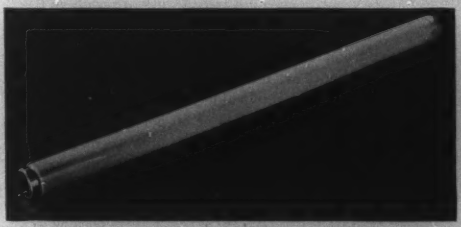

Figure 1. One of the new fluorescent lamps

Design of the Lamp

Choice of lamp dimensions and electrical values is determined not only by the maximum luminous efficiency, but also by numerous other factors, such as useful total light output, adaptability to starting and running on standard line voltages, suitable voltage drop and minimum

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G. E. INMAN and R. N. THAYER are employed in the lamp development laboratory of the Nela Park works of the General Electric Company, Cleveland, Ohio. The authors acknowledge especially the assistance of Doctor B. T. Barnes, of the Nela Park laboratory, for the curves on spectral energy distribution; and of M. A. Edwards, Schenectady, N. Y., for the development of the resonant circuit.

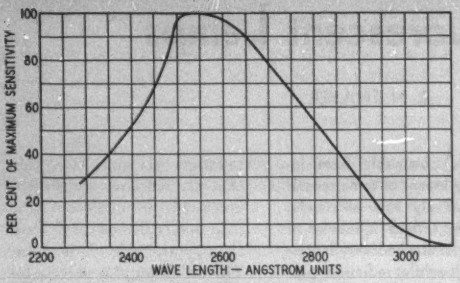


Figure 2. Curve showing relative sensitivity of the zinc beryllium silicate phosphor to ultraviolet radiation of various wave lengths. The peak at or near 2,537 angstrom units is characteristic of several phosphors

power loss in ballast equipment, esthetically pleasing proportions, low surface brightness, and commercial adaptability to manufacture, shipment, and use. Any choice requires compromises, and only a few variables can be considered here. Most activity has been concentrated upon tubes having a diameter of one inch and a current rating of about 0.25 ampere.

Mercury is used as the vapor for the discharge in fluorescent lamps because of its high efficiency in producing short ultraviolet radiation of a single wave length at its resonance line of 2,537 angstrom units. This efficiency is dependent upon the current density to a great extent. The lower currents are more efficient and at 0.25 ampere, which is the approximate value for the lamps described, the conversion efficiency is about 50 per cent. As shown by the example given in figure 2, the fluorescent materials selected produce light most efficiently for ultraviolet radiation of about this wave length, thus forming an ideal combination. No other measured spectral line of the low-pressure discharge in mercury vapor amounts to more than two per cent of the input power; consequently, the line at 2,537 angstrom units reasonably can be considered to be the chief exciter of fluorescence in these lamps. The presence of fluorescent material on the inside of the tube has no appreciable effect on the operation or characteristics of the discharge.

Temperature is a critical factor in the efficiency of producing radiations at 2,537 angstrom units in a low-pressure mercury discharge. Figure 3 shows that the efficiency is highest at 40 degrees centigrade. Consequently, a lamp operating at its most efficient temperature will be only from 15 to 20 degrees centigrade hotter than normal room temperature, and to that extent is a "cold light." Lamps must operate at temperatures higher than this optimum point in order to obtain larger power input and higher light output in tubes of the same dimensions. By using a power input lower than that giving the optimum temperature, efficiency losses from low temperature may be compensated by the advantage of lower current density. In table I the lamps having diameters of one inch operate at the optimum point; the lamps having diameters of one and one-half inches operate below it. The larger diameter was chosen to secure lower surface brightness and less glare. At lower temperatures, such as zero centigrade, very little ultraviolet radiation is produced because insufficient mercury is

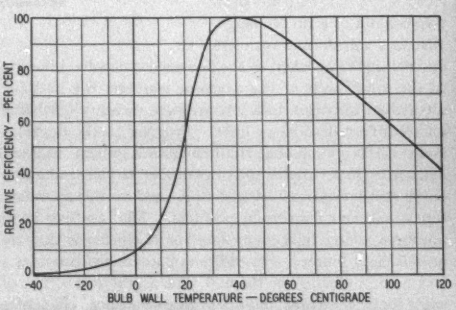


Figure 3. Relative efficiency of production of mercury resonance radiation (2,537 angstrom units) versus bulb wall temperature, for the positive column of a mercury discharge at 0.25 ampere in a tube of one-inch diameter. Fluorescent light output follows this curve closely

vaporized. To maintain normal light output at such an ambient temperature, the lamp must be jacketed or shielded to conserve heat.

Lamp voltage also is an important factor in design. The voltage drop at the electrodes is practically constant, and is almost useless in the production of ultraviolet radiation and light. Consequently, the more the lamp voltage is increased by increasing the length of the tube or decreasing its diameter, the smaller in percentage this voltage loss becomes, as shown in figure 4. Another reason favoring high lamp voltage is that auxiliary loss becomes less as lamp voltage becomes a greater proportion of line voltage. For good stability of this type of discharge, the lamp voltage should not greatly exceed two-thirds of the available supply voltage, the remainder being consumed by suitable reactance.

Table I. Characteristics of Some Fluorescent Lamps

Length	Diameter	Watts	Volts	Amperes	Approximate Lumens Per Watt of a Green Lamp
18 inches	1 inch	15	63	0.27	60
18 inches	1½ inches	15	50	0.33	60
24 inches	1½ inches	20	65	0.35	65
36 inches	1 inch	30	115	0.30	70

Electrical Characteristics of Fluorescent Lamps and Circuits

The operating voltage of a fluorescent lamp may be divided into two components: the electrode drop and the

potential gradient of the positive column. The former is fixed at some value between 12 and 18 volts, depending upon electrode size, cathode emission, and the gas used to fill the tube. The potential gradient is the voltage required per inch of tube to offset energy losses, such as the neutralization of ions at the walls, and the conversion of energy into radiation. The following empirical equations have been found to be valid for experimental lamps operating in the range of from 0.10 to 1.00 ampere:

For tubes one inch in diameter

$$E = \frac{2.73\,l}{0.56 + I} + 12.5 \qquad (1)$$

For tubes one and one-half inches in diameter

$$E = \frac{2.83\,l}{0.75 + I} + 12.5 \qquad (2)$$

where E is the lamp voltage, l the arc gap in inches, and I the current in amperes.

The starting voltage of a fluorescent lamp without preheating of the electrodes is about four times the operating voltage. For example, a lamp 18 inches long and of one inch diameter requires about 250 volts to initiate the discharge. Even at this voltage, a nearby plate or other metal surface connected to one end of the lamp or line, or to ground, usually is required.

Recent work has been concentrated on preheated-electrode starting because lamp life is greatly prolonged and end blackening is reduced by eliminating the sputtering of

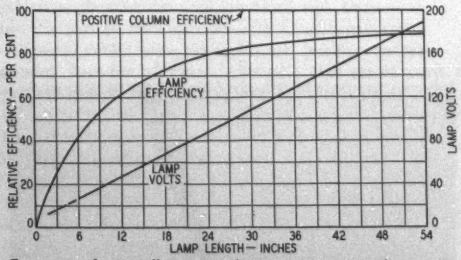


Figure 4. Lamp efficiency relative to positive column efficiency, and volts for various lamp lengths. The arc gap is about one and three-quarter inches less than over-all lamp length

electrode material that occurs with cold starting. Also the required starting voltage is reduced, and may drop to 115 volts, if the electrodes are heated sufficiently. The circuit most easily explained is shown in figure 5*A*. Electrode and reactor design are so correlated that the electrodes are heated to incandescence after the switch is closed. Opening the switch by hand, or automatically by a thermal switch after one or two seconds of heating, produces a surge from the reactor, which easily starts the discharge. A modification of this circuit is a vibrator element built on the reactor, or employed separately. In this instance the

Table II. Approximate Energy Utilization in a 15-Watt Fluorescent Lamp

	Efficiency of Process
Conversion to 2,537 angstrom units	50 per cent
Quantum conversion of 2,537 angstrom units to visible radiation (5,100 angstrom units)	50 per cent
Perfection of phosphor	60 per cent
Transmission of envelope (Covers bulb and base absorption)	90 per cent
Over-all efficiency	13 per cent

circuit is repeatedly opened and closed, with the electrodes gaining heat at each contact until the discharge starts. The operating current then produces a field strong enough to hold the vibrator contacts open. The simple reactor consumes from one to three watts, depending upon its size. The semiresonant circuit shown in figure 5*B* provides simultaneously some voltage boost and electrode-heating current, low power loss, and automatic action with no moving parts. By suitable choice of inductance and capacitance values, and by correct proportioning of the saturation characteristics of the inductor, a combined value of voltage across the lamp and electrode-heating current assures lamp starting. As soon as the lamp starts, it shunts the parallel circuit and runs at an operating current determined by the series unit. Energy lost in the parallel circuit is less than a watt, and the entire circuit may consume only 17 or 18 watts for a 15-watt lamp.

The power factor of most fluorescent-lamp circuits is approximately equal to the ratio of lamp voltage to line voltage. For example, a 65-volt lamp in the circuit of figure 5*A*, assuming a line voltage of 115, operates at about 0.57 lagging power factor. If the circuit constants are predominantly capacitive instead of inductive, the power factor has the same value, but is leading.

Characteristics of the Light Output

The outstanding advantage of the fluorescent lamp is its ability to produce colored light at efficiencies far exceeding those of filament lamps. Experimental 15-watt green fluorescent lamps have operated at 70 lumens per watt. As compared with about 0.3 lumen per watt for certain 60-watt green filament lamps, this represents an efficiency gain of about two hundredfold. The corresponding efficiencies for blue lamps are 18 as compared with about 0.3,

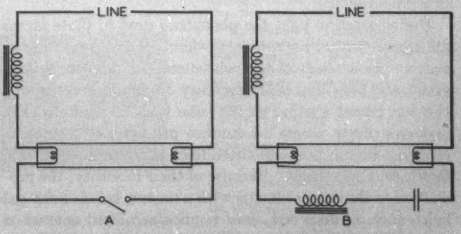


Figure 5. Operating circuits for fluorescent lamps

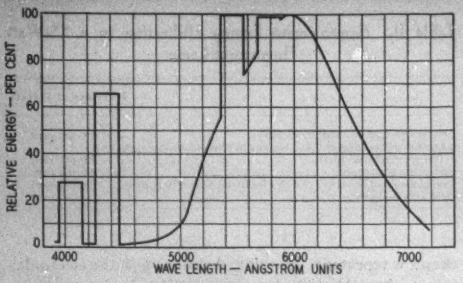


Figure 6. Spectral energy distribution of the radiation from a fluorescent lamp coated with zinc beryllium silicate phosphor. The curve for the phosphor alone is smooth. The block peaks are representations of the visible lines from the mercury discharge, plotted as though 200 angstrom units wide. The combined radiation matches the color, but not the spectral energy distribution, of a black body at about 2,800 degrees Kelvin

a gain of about fiftyfold. For other colors the gain is less spectacular, but still the efficiencies or fluorescent lamps are several times the corresponding efficiencies of filament lamps. Fifteen-watt fluorescent lamps of the same color as daylight have been made with efficiencies of about 30 lumens per watt; obtaining the same amount of light from a filament lamp, with a suitable filter to duplicate daylight, requires 150 watts, or ten times as much power and heat.

On basis for such great gains in special colors is that phosphors inherently produce a certain color, determined by their atomic and crystal structure. As shown in figure 6, spectral-energy distribution measurements typically show a peak region, which in this instance is at 5,950 angstrom units (yellow). In filament lamps, color must be produced from a source giving a continuous spectrum by the subtractive method of using a filter that absorbs all light except light of a desired color. A second basis for efficiency gains is that a large percentage of input energy is converted into usable radiant energy. A 40-watt filament lamp, for example, converts about seven per cent of its input energy into visible radiant energy, and most of the remainder is converted into infrared radiation, which is not convertible into light. Despite the efficiencies of utilization of a fluorescent lamp as shown in table II the net percentage of energy available for light production is about twice that of filament lamps.

Under external light the phosphors used in these lamps all appear white, regardless of their color during fluorescence. As a result of this whiteness, the familiar yellow, green, and blue lines of the mercury discharge pass through the fluorescent coating on the tube with little absorption, and contribute about 3.5 lumens per watt to lamp efficiency. Figure 6 shows these lines superimposed on the fluorescent spectrum. Because of their intensity, the production of fluorescent lamps with a narrow band of colored light, such as deep red, may require a colored enamel or filter. On the contrary, where it is desired to avoid any sharp peak of energy, as for daylight lamps, several phosphors may be mixed together to give a more nearly uniform spectral energy distribution.

Some phosphors, such as green and pink, inherently possess some lag, and continue to emit light after the exciting source is removed, so that 15-watt fluorescent lamps using such phosphors show no more flicker on 60-cycle supply than do regular 25-watt 115-volt filament lamps. Other phosphors, such as blue, have no measurable lag, and follow closely the starting and extinguishing of the discharge on each half of the cycle. The condensation of mercury at low temperatures not only lowers the production of ultraviolet and of visible light, but raises the starting voltage so much that special ballast equipment may be required; hence, fluorescent lamps are best used indoors, or outdoors in mild weather.

About every new type of lamps the engineer asks, "What is its effective life?" In the use of fluorescent lamps, as in vapor lamps generally, useful life may be limited either by the number of times the lamp is started or by the loss of light with continued operation. Frequent starting of lamps causes eventual failure to start, because the emissive material sputters off. If lamps are operated continuously, or for several hours following each start, they may last several thousand hours, but at steadily decreasing light outputs until replacement is justifiable economically. The amount of decrease varies with different phosphors. Fluorescent lamps under average operating conditions are expected to last longer than filament lamps and to have lumen maintenance comparable with that of filament lamps of the vacuum type.

One suggested use of the new tubular fluorescent lamps is for flooding ceilings with colored light. As shown here the lamps are concealed within a trough suspended from the ceiling

Television Transmission by Coaxial Cable

By M. E. STRIEBY
MEMBER AIEE

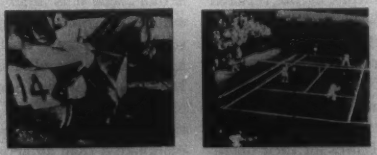
Coaxial cables were developed originally to provide large groups of telephone channels, but their wide frequency range has led to experiments with the transmission of signals for television. High-quality signal generating and receiving equipment was used to send 240-line motion-picture images from New York to Philadelphia, as described in this article; distortion introduced by the wire-line circuits could be made so small as to be inappreciable.

REPORTS that have been made on the progress in television development increase the expectation that the commercial broadcasting of visual programs soon will be realized. In anticipation of this, the Bell Laboratories has been engaged for some time in the development of wire-line circuits for transmitting television signals between studios and broadcasting transmitters, or between cities, as may some day be required if television follows in the footsteps of sound-program broadcasting.

The wide frequency bands required for television and the dearth of available frequencies appear to force the broadcasting of television signals into the ultrahigh-frequency range. At these high frequencies, the coverage which can be obtained from a broadcasting station is very limited as compared to that obtainable in the sound-broadcasting frequency range. Hence, if television programs are to reach large sections of the country simultaneously, the provision of interconnections between large numbers of television broadcasting transmitters will become even more important than it is today for sound broadcasting.

Coaxial cables have received much publicity as transmission lines for television. Actually that use is a by-product that had little or nothing to do with the original conception. The idea of a coaxial cable or other medium for the transmission of very broad frequency bands originated as a telephone development in the United States.[1] The first lengths of such cable for broad-band transmission were made here and its first use for the transmission of a large number of simultaneous telephone conversations was between New York and Philadelphia.[2] In the United States the important reason for developing coaxial cable systems was, and still is, that they appear to offer material economies in the provision of large groups of long-distance telephone facilities. Television has been incidental.

Recently experiments have been made on the transmission of television signals over the coaxial cable between New York and Philadelphia. This cable contains two coaxial conductor units within a lead sheath about seven-eighths inch in diameter as indicated in figure 1. Two coaxial units were provided because, for long-distance telephone operation, four-wire operation is preferable, one coaxial unit being employed for transmission east to west and the other west to east. Each coaxial unit is made up of a 13-gauge inner conductor on which hard-rubber disks have been placed at intervals of three-fourths of an inch. The outer metallic tube is made up of nine overlapping copper tapes so designed that they form essentially a solid copper tube about 20 mils in thickness and 0.267 inch in inside diameter.



Photographs of the receiving tube during transmission; in the tennis match the ball itself shows and its movement could be followed

The transmission loss of this circuit as a function of frequency is shown on figure 2 together with the portion of the attenuation that is contributed by conductance losses. Inasmuch as the intention is to use these conductors at very high frequencies, a high-grade insulating material was used with the result that the conductance losses are small. It should be noted that the attenuation increases very nearly as the square root of the frequency.

In order to transmit high frequencies over long distances, a great deal of amplification is obviously required. The New York–Philadelphia cable was initially equipped to handle a band of 1,000,000 cycles. Its over-all attenuation at one megacycle is approximately 600 decibels. In order to reduce this to a usable amount, ten repeater points were provided at intervals of about ten miles, each having an amplification at the top frequency of about 60 decibels. These repeaters were so designed that they provided less gain at low frequencies than at high frequencies in approximately the same degree as the line had less attenuation. To make up for certain cumulative irregularities an equalizer was built and added to the over-all circuit. The net result was a transmission path which had approximately zero loss over the whole band which it was desired to use from 60 to 1,000 kilocycles as shown in figure 3.

Another complicating factor, however, is involved, as

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Figure 1. Section of the New York–Philadelphia coaxial cable

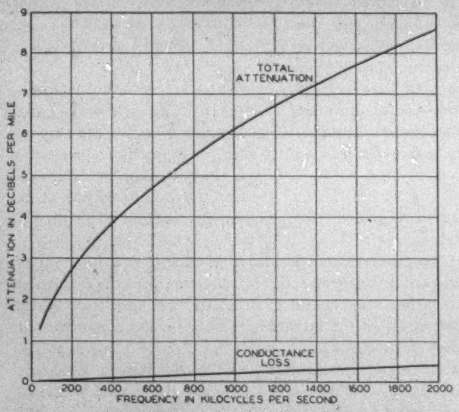


Figure 2. Attenuation per mile of the New York–Philadelphia coaxial cable, and proportion of that attenuation caused by conductance losses

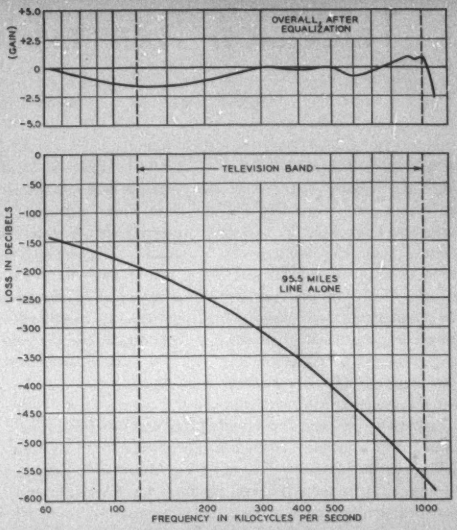


Figure 3. Over-all attenuation of the New York–Philadelphia cable without repeaters and the net attenuation after repeaters and equalizers had been provided

is the case with all long wire circuits, namely, the variation encountered with changes in temperature. The loss in a ten-mile repeater section varies materially from summer to winter. If the cable is hung overhead, this variation is about as shown in figure 4 and amounts to a change of about plus or minus seven per cent in the attenuation. If the line is buried underground at the normal depth used for telephone cables, the actual variation is about one-third as much. Automatic transmission regulators were developed to compensate for these changes. These regulators depend, for their operation, on the transmission of a pilot channel. At each point where it is desired to regulate the transmission, the pilot channel is selected by a very narrow band filter and its amplitude used to control an automatic device which changes the gain of the repeater until the amplitude of the pilot at the output of the repeater reaches a certain predetermined value. The regulators on the New York–Philadelphia circuit have operated with such accuracy that it has been unnecessary to make manual adjustments to take care of temperature changes.

The repeaters used along this route were novel in that most of them were placed in small iron boxes located at convenient points along the line. Power for their operation was transmitted at 60 cycles over the coaxial cable itself. Figure 5 shows one such repeater.

The coaxial system between New York and Philadelphia was designed to provide 240 telephone circuits. Skeleton terminal apparatus was installed at New York and Philadelphia to test out such operation. This apparatus has been described[2–4] before the AIEE and will not be discussed here. Suffice it to say that methods and equipment have been developed which enable a wide band to be split up so as to obtain hundreds of telephone channels.

For television transmission a quite different problem existed—namely, can very-wide-band systems be used for the long-distance transmission of these complicated signals? In planning tests to be significant of the operation of the cable system for such signals, it was important to obtain as nearly as possible an ideal television signal and as nearly as possible an ideal television receiver. In this way it was hoped that any defects in the cable transmission itself could be discovered.

Signal Generator

Although television implies the transmission of an actual scene it is much more satisfactory for engineering studies to transmit a motion picture, since exactly the same picture can then be transmitted over and over again as the circuit elements are changed or adjusted. Moreover, it was decided to use mechanical scanning to obtain the most nearly perfect signal possible, and with this form of scanning a film can be much more brightly illuminated than an actual scene and hence is much easier to use. Because of these factors a motion-picture film was chosen as the material for the recent experiments.

The scanning disk used in these tests was developed

under the direction of H. E. Ives at the Bell Laboratories. It consists of a six-foot disk with a circle of 240 lenses near its outer edge. The arrangement is indicated schematically in figure 6. Light from a powerful incandescent lamp behind the disk, passing through one lens at a time, is focused by the lens to form on the film a small dot of light about three-thousandths of an inch square. The lenses in the disk are spaced by a distance equal to the width of the picture, or a little less than an inch, and as the disk rotates, each spot is moved rapidly across the picture. The film is carried at a uniform rate downward behind the disk at such a speed that the successive holes throw their light in successive rows across the picture one above another. The film moves one frame for each revolution of the disk. A photosensitive surface mounted behind the film picks up the light transmitted through it, and produces a complex electric current corresponding to the variations of light in the picture. Figure 7 shows a photograph of the housing in which the disk is mounted. This scanning arrangement produces a picture of 240 lines, 24 frames per second. It was recognized that 24 frames per second were not sufficient to avoid flicker but this choice simplified the scanning apparatus and it was believed would not interfere with engineering tests.

Signal Frequency Range

In order to understand what frequency is required to transmit an image scanned in this way, reference may be made to the diagram shown in figure 8. Of course, actual television will not ordinarily deal with such a picture, but by means of it an approximate visualization of the problem can be obtained. A desired definition of 240 lines was chosen and it was decided that the transmission should provide for square picture elements as indicated in the figure. The shape of the picture which it was convenient to use with this scanning disk is wider than it is high in the ratio of seven to six. This differs somewhat from the standard aspect ratio of four to three, but is easily taken into account. The total number of picture elements in a frame is then $240^2 \times 7/6 = 67{,}200$.

If the smallest picture element to be transmitted is a single block, then the distribution of light and shade over the block is unimportant. The average brightness over each block is what counts. Obviously, a simple approximation is a sine wave as shown at the bottom of the picture. This wave has one half cycle for each block and is as high a frequency as there is any profit in transmitting for this diagram.

The top frequency needed for such a picture can then be calculated. The number of square elements in the picture as just computed is 67,200. As each of these elements represents one-half cycle, this figure is divided by two, giving 33,600 cycles per frame. As similar frames are reproduced 24 times a second, the result is $24 \times 33{,}600$ or 806,400 cycles per second. In a real moving picture, other frequency components may exist at all other fre-

Figure 5 (above). Testing an unattended repeater near Dunellen, N. J.

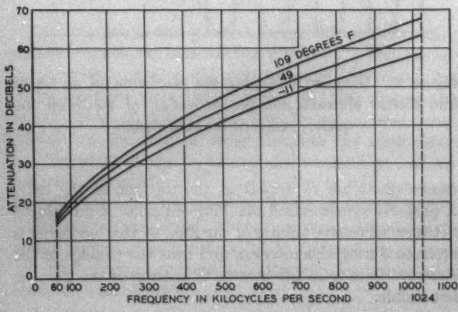


Figure 4 (left). Attenuation of the New York–Philadelphia type of cable under widely different temperature conditions

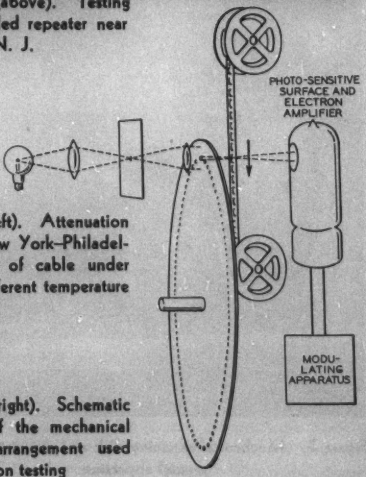


Figure 6 (right). Schematic diagram of the mechanical scanning arrangement used for television testing

quencies from 800 kilocycles down to and including direct current. The d-c or zero-frequency component controls the general level of brightness of the picture. Where the general level of brightness changes slowly, it results in a component of very low frequency. A composite picture can be imagined which will produce a pronounced component at any given frequency, hence, it is deemed important to transmit the entire band from 0 to 806 kilocycles.

Receiving Device

At the receiving end an effort was made to obtain as high a degree of fidelity of reproduction as possible. No small factor in the success of the recent experiment was the special cathode-ray tube, designed by C. J. Davisson, used at the receiving end to display the transmitted picture. Some of the features of this tube are indicated schematically in figure 9. A stream of electrons from the cathode passes through a series of electron lenses which focus a narrow beam on an aperture 0.006 inch square. Between the lenses and the aperture, however, are two modulating plates connected to the incoming circuit in such a way that there appear on these plates potentials varying according to the voltage of the incoming signals. The effect of potential on these plates is to deflect the electron beam, and the conditions are such that at maximum strength of signal practically the entire stream of electrons passes through the hole and forms a brilliant spot of light on the front of the tube. As the signal decreases in strength, the electron stream is more and more deflected; less electrons pass through the aperture, and the illumination on the sensitized end of the tube decreases.

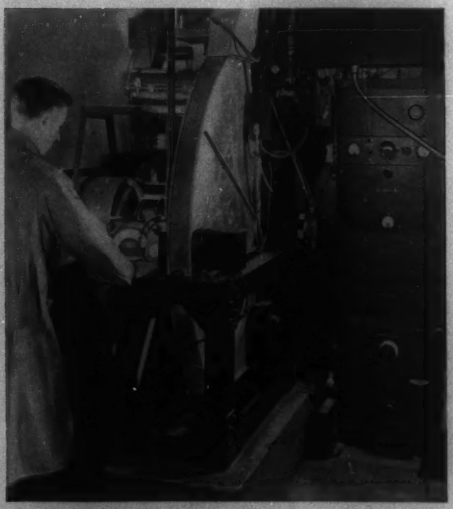


Figure 7. Mechanical scanning disk and associated experimental apparatus

In addition to these modulating plates, and placed between the aperture and the front of the tube, are two other pairs of plates mounted in planes at right angles to each other. The potential on one of these sets of plates, controlled by a frequency of 5,760 cycles, which is the frequency at which successive lines are scanned, varies in such a way that the beam of electrons passing through the aperture is swept across the front of the tube from left to right, exactly in synchronism with the scanning beam at the sending end. After the beam reaches the farther side of the picture, the potential on the plates is suddenly changed, and the beam is rapidly moved back to begin the next line. Due to a black mask down the far side of the film being scanned, there is no signal during this very short period while the voltage on the plates is changed, and thus the electron beam is deflected from the aperture and is not visible on the front of the tube during its return.

The potential on the other pair of plates is controlled at a frequency of 24 cycles per second, which is the rate of scanning successive frames. The effect of the potential on these plates is to deflect the electron beam downward in synchronism with the motion of the film at the sending end. This results in the passage of the electron beam across the front of the tube in successive rows, one below another. After the last row has been scanned, the voltage on the plates is changed and returns to the value that

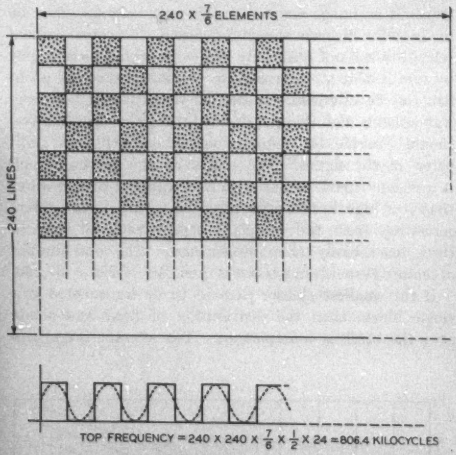


Figure 8. Diagram illustrating the resolution of an image into picture elements and the derivation of maximum frequency required for transmission

causes the beam to appear at the top line of the tube. A properly synchronized blanking-out pulse is introduced between successive frames of the film, so that no signal is received during this interval, and thus the passage of the electron beam from the bottom to the top of the frame is not visible.

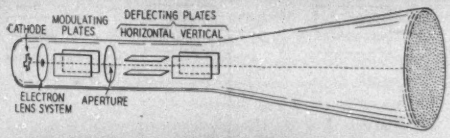


Figure 9 (above). Schematic diagram of the special cathode-ray tube used for viewing transmitted images

Figure 10. One of the special cathode-ray receiving tubes

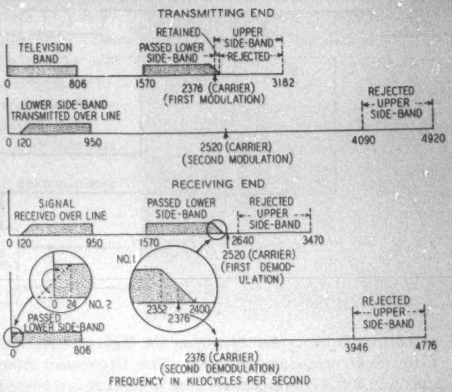


Figure 11 (right). Schematic diagram illustrating the processes of modulation and demodulation used in transmitting television signals over the coaxial line

Figure 10 shows a photograph of one of these cathode-ray tubes. Because of the tube's superior design, the image is very sharp over the entire field and a wide range of brightness is secured. The chief factors in its success are the sharp focusing by the electron lenses, the linear deflection of the beam at the aperture, and the great length of the tube, which makes it necessary to deflect the electron beam over only a narrow angle to cover the seven-by-eight-inch field. Since this trial was a test to determine the capabilities of the system, such matters as size and cost, which would be important with commercial receivers, were not controlling.

Modulation System

The frequency band which was generated at the sending end as noted before was 0 to 806 kilocycles. The coaxial-cable system used could not transmit this band, because repeaters were not designed to pass frequencies below about 60 kilocycles. This limitation was incorporated in the original design because the cable offers insufficient shielding to various disturbances at low frequencies. For television transmission it was necessary, therefore, to raise the television-signal band to a higher-frequency position before attempting transmission over the line. Several considerations led to the decision to raise the entire frequency band 144 kilocycles for transmission over the coaxial cable.

Where such a wide frequency band is to be raised by an amount less than the width of the band itself, a single modulation is not generally satisfactory. The products of modulation include the original frequency band as well as the upper and lower sidebands, so that in the lower sideband there will be a confusing jumble of frequencies in the modulator output. For this reason a double modulation method was used for the recent experiments.

The modulating scheme employed can be followed with the help of figure 11, which shows the two modulating steps at the sending end and the two demodulating steps at the receiving end in four lines beginning at the top. A carrier of 2,376 kilocycles is used for the first modulation, which results in a lower sideband from 1,570 to 2,376 kilocycles and an upper sideband from 2,376 to 3,182 kilocycles. The carrier itself is eliminated in the balanced modulator. The output of this modulation is passed through a filter, but because the two sidebands touch each other at 2,376 kilocycles, the filter cannot cut off all the upper sideband. At the output of this filter there is thus the lower sideband plus a small amount of the lower part of the upper sideband. The upper sidebands from all subsequent modulations are readily eliminated by filters because of the wide separation.

The carrier for the second modulation is 2,520 kilocycles, and the lower sideband extends from 950 down to 144 kilocycles plus the vestigial upper sideband remaining from the first modulation which extends down to 120 kilocycles. The high-pass filter following this modulation is accurately designed to pass with controlled attenuation a group of frequencies just above 144 kilocycles and the vestigial sideband. The resulting single sideband, extending from 120 to 950 kilocycles, is then passed over the coaxial cable.

At Philadelphia the received signal, together with a carrier of 2,520 kilocycles, is applied to the first demodulator, and the lower sideband, from 2,400 down to 1,570 kilocycles, is passed to the second demodulator where a carrier of 2,376 kilocycles is applied. The lowest frequency of the lower sideband, 1,570 kilocycles, is con-

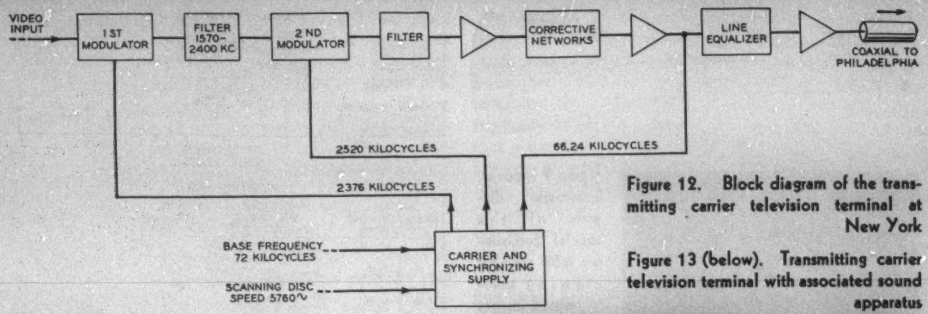


Figure 12. Block diagram of the transmitting carrier television terminal at New York

Figure 13 (below). Transmitting carrier television terminal with associated sound apparatus

verted to 806 kilocycles, becoming the highest frequency of the final demodulated band. The frequencies from 2,352 to 2,400 kilocycles have been somewhat attenuated by the high-pass filter mentioned above. The second demodulating carrier, 2,376 kilocycles, falls in the middle of this attenuated band as shown in inset number 1 in figure 11. Frequencies extending about 24 kilocycles above the carrier are inverted by the demodulation, and superimposed upon the corresponding frequencies just below the carrier. The magnitude and phase of these components are proportioned by the high-pass filter and an equalizer so that the over-all result, when they are superimposed, is an essentially flat transmission band from zero to 806 kilocycles.

These steps of modulation involve many difficulties. In the first place, the signal level must be carefully controlled so that on the one hand it does not sink into the background noise, while on the other hand it must not be raised to such high levels that unwanted modulation products are produced in too great magnitude. The first modulator presents some special problems. It must accommodate all frequencies from 0 to 806 kilocycles. In order to eliminate the carrier, it must be balanced out to a very high degree—about 80 decibels below the signal level in this case. The reason the carrier must be wiped out so completely is that the zero-frequency component of the signal is identical with the carrier at the output and hence the true d-c value of the signal must be exceptionally free from carrier interference.

Referring to figure 12, the next piece of apparatus is a band filter to eliminate the video signal and cut off the top edge of the band. Then follows the second modulator which is quite conventional. A low-pass filter is next and is very important as it performs part of the function of cutting off and adjusting the vestigial sideband. Then follows an amplifier, a predistorting network to equalize partially the amplitudes of the different components of the signal, an aperture equalizer to correct for the fact that the scanning spot is of finite size, a terminal equalizer to make up for irregularities in the over-all setup, and other amplifiers.

The carrier apparatus at the sending end is shown by figure 13. It is mounted in rather conventional form except for the first modulator which was arranged to minimize the effect of low-frequency vibrations. At the receiving end about the same apparatus is required in the inverse order and it will not be discussed in detail.

Carrier Supply

Another feature of this system was the provision of accurately spaced carriers for the various modulating operations. The Bell System four-kilocycle standard was used to produce a 72-kilocycle (18th harmonic) base-frequency signal which could be transmitted over the line and so tie the transmitting and receiving ends together. From this, by harmonic generation, the carriers used in the two steps of modulation were produced, being the 33d and 35th harmonics.

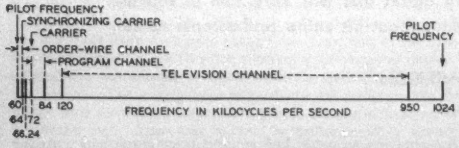
To synchronize the scanning at the receiving end with the transmitting disk required another direct tie. The disk is driven by a d-c motor and its speed cannot be kept very constant. By means of an auxiliary lamp and photoelectric cell, the frequency with which one scanning line followed another—approximately 5,760 per second—was obtained. This was modulated with the 72 kilocycles

mentioned in the preceding paragraph and transmitted over the line as a lower sideband at 66.24 kilocycles. At the receiving end by demodulation, the exact line speed, approximately 5,760, is obtained and used to drive the horizontal sweep. The vertical sweep is obtained by generating the 240th subharmonic of this—namely, 24 cycles per second.

Line Equalization and Test Results

With reference now to the line transmission problem, the signals which might be transmitted in the general case are indicated in figure 14. They include the pilot channels used for automatic transmission regulation at 60 and 1,024 kilocycles. For convenience, one telephone channel with a carrier at 64 kilocycles is indicated as an order wire, and a wide-band program channel with carrier at 84 kilocycles to transmit the sound. These, of course, could be provided with ordinary telephone facilities. The base frequency of 72 kilocycles and the disk synchronizing sideband at 66.24 kilocycles are also included. For the television signal itself the band from 120 to 950 kilocycles is provided. Actually in the tests to Philadelphia, automatic regulation was not needed and a separate wire line was used for synchronization.

It was necessary to provide networks and equalizers to insure that the coaxial line did not distort the ultimate image by unequal attenuation, resulting in amplitude distortion, or by unequal time of transmission, causing phase distortion. The actual attenuation characteristics of the line[5] and the over-all result were shown in figure 3. The



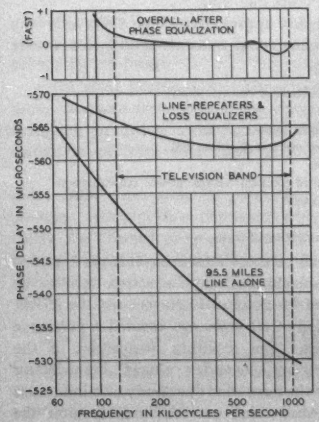


Figure 14 (above). Frequency allocation for a television transmission system with associated control circuits

Figure 15. Phase delay of New York – Philadelphia television circuit

Figure 16. Two-megacycle amplifier under development for experiments on the coaxial cable

requirements for phase distortion are rather difficult to meet. The details in the scanned picture result in various frequencies of the electrical signal, and if these details are to appear in the reproduced picture in the same relative position as in the scanned picture, it is essential that all frequencies be received in very closely the same relative time relationship as they are generated. With reference to figure 8, the assumption was made that no picture element could be displaced by more than about half its width. This led to the decision to hold frequencies between 806,000 and 3,000 cycles to a delay distortion of about 0.3 microsecond. For a similar degradation of detail in the vertical direction, the permissible delay distortion is 280 times as great. In a system of this type, this is very easily obtained. The actual circuit roughly met these requirements as indicated by figure 15, which shows the phase-delay characteristics of the line, repeaters and loss equalizers, and of the over-all circuit at the frequencies used for transmission.

Noise or interference is very annoying in television transmission, and pattern, or single-frequency interference, is particularly objectionable. The permissible noise or interference depends on the amplitude range of the reproduced picture. During these experiments, it was found that a substantially linear response could be obtained over a signal-current range of about 20 decibels—(a brightness ratio of ten to one). The actual reproduced pictures considerably exceeded this range—in fact a brightness ratio of 50 or 100 to 1 was realized. In these tests it was found desirable to hold random interference down about 40 decibels below the maximum signal, and pattern interference down at least 15 decibels more.

The engineers who worked on the system, and outside experts who observed it, expressed the opinion that the reproduced pictures in Philadelphia were substantially the same as those seen on a similar receiving device in New York, thus showing that the cable system itself introduced no appreciable distortion.

Further Development Now in Progress

As a result of the experimental transmission of the pictures over the coaxial cable from New York to Philadelphia it has been proved that wide-band signals of the type

required for television can be satisfactorily transmitted over a coaxial-cable system, and that in such transmission the distortion introduced by the wire-line circuits can be made so small as to be inappreciable, in its effect on the received picture.

The work on these very-wide-band systems has only begun and repeaters and terminal apparatus are now under development capable of handling wider bands of frequency. At the present time work is under way on a two-megacycle system for telephone transmission and a trial installation is being made between New York and Princeton. The system will transmit a frequency band of about two megacycles corresponding to a capacity of 480 telephone circuits. Repeaters on this system will be about five miles apart and will consist of unattended boxes somewhat smaller than the one-megacycle repeaters illustrated hereinbefore, and placed either in manholes or on poles along the route. Within these boxes there are placed two amplifiers, one for eastbound transmission, the other for westbound, together with the necessary filters and power-supply apparatus. The actual amplifiers themselves are quite small compact units, one of which is shown in figure 16. Two megacycles, of course, is not a sufficiently wide band to transmit the present Radio Manufacturers Association standard 441-line television signal, but is a logical step toward more economical telephone circuits. Development is also under way on amplifiers capable of transmitting three-megacycle bands of frequency, which should amply satisfy the requirements for transmitting the 441-line television signals now envisioned as standard by the television industry.

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Today's Opportunity for the Young Engineer

By cultivating a practical point of view toward today's difficult situation the young engineer may gain experience at the very outset that will assist him in solving problems likely to recur again and again throughout his entire professional career

By W. H. HARRISON
PRESIDENT AIEE

YOUNG MEN these days ponder over the future, speculate on what it holds, not infrequently become so perplexed at the outlook that they wonder whether there is much in store for them—whether the industrial expansion has not run its course. This all too general train of thought prompted me to retrace the written record back to the period when the telephone received its first recognition, which was the birth of this great industry. This was at the Centennial Exposition held in Philadelphia, Pa., in 1876 to celebrate a century of our national life. This exposition evidenced in tangible form the tremendous advances of our material prosperity as contrasted with that of the old world. The marvels of mechanical ingenuity and of science and invention, and the engineering displayed there, must have stirred creative imagination as never before; and must have had a strong influence upon the years following.

In the brief period of approximately ten years following this exposition, numerous significant developments were initiated, including:

The commercial application of the telephone.
The electric arc lamp.
The electric incandescent lamp.
The multiple system of electric distribution.
Hydroelectric stations.
The a-c transformer and modern electric-power transmission.
The electric street railway.
Color printing.
The steam-electric generating station.

As an outgrowth of these advances, this same period witnessed the organization of many societies, such as the American Society of Mechanical Engineers and the AIEE. This ten-year period of 60 years ago created a milestone of human progress. The resulting integration of the constructive efforts of centuries almost immediately manifested itself in the formation of entirely new industries of unprecedented size which were destined to alter the

Notes used by President Harrison at a conference of the Student Branches of the AIEE Great Lakes District held April 22–23, 1938, at the University of Illinois, Urbana.

In transmitting these notes for publication Mr. Harrison states: "In the preparation of these notes I discussed the subject with my associate O. W. Eshbach to whom I am indebted for some helpful suggestions."

entire scheme of human relationships. Their operation and influence on our lives and customs have revolutionized social intercourse, industrial relations, and management in such a way that the end is not yet in sight.

All the conveniences of transportation, communication, light, power, and a host of other things, are monuments of the material achievements that have resulted. In the early stages of this industrial revolutionary period, as there was before, as there has been ever since, and as there probably ever will be, there was much concern as to where all these scientific advances were leading the nation. We were reminded then, as we are now, that the application of science and engineering must be slowed up lest we suffer dire consequences from the nation's inability to assimilate these advances. In 1886 Carroll D. Wright, United States Commissioner of Labor, in the introduction to his annual report of that year made the following significant statement:

"The rapid development and adaptation of machinery in all the activities belonging to production and transportation have brought what is commonly called overproduction, so that machinery and overproduction are two causes so closely allied that it is quite difficult to discuss the one without taking the other into consideration. . . . On all sides one sees the accomplished results of the labor of half a century. From a financial point of view, these accomplished results should always be good, but in many cases it is apparent that undertakings have proved deceptive and governments become needy and some . . . insolvent. Whatever may have been the financial results, industry has been enormously developed, cities have been transformed, distances covered, and a new set of economic tools has been given in profusion to rich countries, and in a more reasonable amount to poorer ones. What is strictly necessary has been done oftentimes to superfluity. This full supply of economic tools to meet the wants of nearly all branches of commerce and industry is the most important factor in the present industrial depression. It is true that the discovery of new processes of manufacture will undoubtedly continue, and this will act as an ameliorating influence, but it will not leave room for a marked extension, such as has been witnessed during the last 50 years, or afford a remunerative employment of the vast amount of capital which has been created during that period. The market price of products will continue low, no matter what the cost of production may be. The day of large profits is probably past. There may be room for further intensive, but not extensive, development of industry in the present era of civilization."

This quotation and many others that are available are characterized by a common factor: Little or no hope is offered for the future.

While most people during times when the outlook is most uncertain seem to hold the views illustrated by the foregoing quotation, some have the foresight and imagination to perceive that there is a still greater period ahead, that the general trend of our social welfare is upward from generation to generation, from century to century, with periods of depression which interrupt temporarily the upward progress. In 1830, at the time of a serious depression in Great Britain, Macaulay, the famous British historian, published an essay in the Edinburgh *Review*. Only a small part of it is quoted:

"If we were to prophesy that in the year 1930, a population of 5 millions, better fed, clad, and lodged than the English of our time, will cover these islands . . .—that machines, constructed on principles, yet undiscovered, will be in every house—that there will be no highways but railroads, no travelling but by steam—that our debt, vast as it seems to us, will appear to our great-grandchildren a trifling encumbrance, which might easily be paid off in a year or two—many people would think us insane. . . .

"Hence, it is, that though, in every age, everybody knows that up to his own time progressive improvement has been taking place, nobody seems to reckon on any improvement during the next generation.

"We cannot absolutely prove that those are in error who tell us that society has reached the turning point—that we have seen our best days. But so said all who came before us, and with just as much apparent reason. . . ."

Here we are in the 1930's. We find ourselves with the rest of the world in a perplexed state of confusion. Young men on the threshold of their business careers are wondering what the future holds for them. They are wondering how well they shall be able to readjust their lives to the tune of tomorrow. They will do well to recognize that life is one continual period of readjustment. The readjustment of tomorrow is the first of a series. It now seems terribly difficult. It will not be difficult at all.

If a biologist, a historian, a politician, and an engineer were asked what the future holds, a different answer probably would be received from each. While all the answers would be interesting, the historian's would be most helpful in our day-to-day lives. In history we find recorded the experience of the human race since the earliest days of civilization. It is difficult to conceive how we can judge the probabilities of the future, except by the experience of the past. In spite of the dire prophecies that have been made, history records on the whole a gratifying, a really fantastic result.

Engineers are trained to be realistic, and not given to flights of fancy. To realistic men, on the surface it would seem, particularly in the electrical field, that hardly any frontiers are left to explore and to conquer. There is some reason for the query as to whether the industry which captured the imagination of our fathers by its feats of wonder and by its promises of immense growth and importance in the world, any longer offers romance. Electricity is so commonplace, it so regulates our day-by-day existence, that one might wonder what is left.

I am not a crystal gazer and have no power of prophecy. As a matter of fact the *present* always has engrossed me, for I believe that settling the problem of *today* frequently settles the problem of tomorrow. But as I have seen something of the road perhaps I can point out a few things that may help and encourage young electrical engineers about to embark upon their professional careers.

I am not going to suggest there are plenty of opportunities because at this moment I do not know that there are. Today's graduates are going to find it a good deal harder to find jobs than the graduates of my generation. In a sense this is a great advantage because it requires the young engineer at the very outset of his professional life to tackle a problem of the kind that may recur again and again as long as he works and lives. Today's graduates face a different environment which they are perfectly innocent of causing, and the problem will be to adjust themselves to it. I cannot emphasize too strongly the importance of cultivating a practical point of view toward it. There is no point in feeling resentful or sorry or helpless.

As creatures of the world we cannot live effectively unless we are in tune with our environment whatever it may be, and it is always changing.

In one form or another I presume most electrical-engineering graduates will seek their livelihood in the electrical industry. They have shown good sense in selecting this field. The very fact that the industry regulates our daily lives—and all one need do is glance at the skyline in the evening to have this vividly brought home—places a great responsibility upon those in it to continue further progress. Young electrical engineers are fortunate that it is an industry impelled by the spirit of progress; of service; that it is still permeated by enthusiam for the job it has to do and by an eagerness to find better ways of doing it.

We sometimes hear that there are too many lawyers, too many doctors, too many engineers. There may be too many lawyers, too many doctors—I don't know; but I do know there are not too many engineers. In the engineering profession as a whole there are roughly a quarter of a million engineers. Schools graduate 8,000 or 9,000 new engineers each year—barely enough to replace yearly losses due to mortality, changes, and other factors, which represents about four per cent. Increase in population also is a factor.

It would be idle for me to attempt to point out those things which on the surface all agree need continuing attention. Our best steam generating plants operate at an efficiency of 30 per cent; there are the problems of transmission and distribution—system stability under faulty conditions; new markets need to be developed; opportunities in the field of application are limitless.

One of the things that may surprise the young engineer is the extent to which nontechnical considerations enter into engineering problems. Let me cite a typical engineering problem in which broad social and human consideration played an important part. The problem consisted of moving an old eight-story telephone building to a new location without disturbing the functions normally performed therein, which included on the first floor business transactions with the public. The building weighed 11,000 tons, covered one-quarter acre of ground, and contained about 300 employees half of whom were women. It was moved 50 feet in one direction, then rotated through a 90-degree angle. The problem involved more than the maintenance of elevator, water, gas, light, and plumbing services; in order to obviate the possibility of panic among the employees, it was necessary to create a feeling of confidence in the safety of the operation.

Perhaps not all electrical-engineering graduates intend to be electrical engineers or even engineers at all; but whatever occupation they choose I think they will find their technical training of great value. They have learned to think quantitatively and to deal with facts. They have learned to tear their problem down to its elements and to draw sound conclusions from such data as are available. They have learned to be rigorously honest with their thinking. They should not think, therefore, that their technical preparation unsuits them for other things.

I want to say just a brief word about the national engineering societies and the American Institute of Electrical Engineers in particular. The vast and extensive current commercialism of new ideas brought about by research in both college and industry make it almost impossible to include in curricula much more than the basic fundamentals necessary to understand them. It becomes necessary, therefore, for men in industry to identify and associate themselves with such groups or agencies as have been created for purposes of professional advancement.

Our Institute was organized for the purpose of advancing the theory and practice of electrical engineering and its allied arts and sciences, and to maintain a high professional standing among our members. Our technical forums and publications are characterized by emphasis on scientific achievement, the development of technical proficiency, and concern for the public welfare wherever engineering knowledge and experience are involved.

In rendering service to the community, state, and nation, the societies are motivated by unselfish purposes and fairness in action both of which have found expression in codes of ethics or principles of professional conduct. Association with this professional group is characterized not only by the possession of a common technical knowledge and understanding, but also by an attitude of mind and character that implies conduct in keeping with the higher ideals of American social and industrial life.

Engineers, in order to keep pace with scientific and industrial advances, and in order to develop qualities of character and personality that make heart and mind sensitive to motives governing human behavior and their consequences as affecting others, should take advantage of the opportunities offered by membership in their national professional societies.

Finally, let me remind the young engineer that in his few years at college he has had time to do no more than make a fair beginning on his job of educating himself. He must then earn a living, and he may want to marry; certainly he will find many things interfering with his most important task, namely, the continuing of his education. But one thing is as sure as sunrise: If earning his living, poker games, movies, marrying and raising kids, or staying single and raising Cain, or anything else under the sun causes him to forget the fact that he somehow must continue to get an education, he is doomed. He will settle down into a more or less comfortable rut; he will do what other engineers direct him to do as long as he stays in the profession. A man may fail in college courses, and this usually eliminates him as a potential engineer; he may pass his college courses successfully, but within the next five years eliminate himself just as effectively.

Today's engineering graduates have the heritage of great schools, the background of sound training. They should hold fast to individual industry, effort, and integrity as these are the most cherished possessions of this nation of ours. These principles must prevail, and young engineers must safeguard them for the generations to come.

The road of tomorrow is challenging—the opportunities plentiful—the rewards great. "There is no failure except in no longer trying."

News

Of Institute and Related Activities

1938 Summer Convention Program Completed

THE annual summer convention of the Institute to be held in Washington, D. C., June 20–24, 1938, offers many attractive features. The nation's capital is the center of scenic and historical interest and the summer convention committee has taken full cognizance of this fact in arranging an excellent program of trips, sports, and entertainment, the details of which were announced in ELECTRICAL ENGINEERING for May 1938, pages 221–4. Convention headquarters will be in the Mayflower Hotel.

BUSINESS AND TECHNICAL PROGRAM

In addition to the annual business meeting, conference of officers, delegates, and members, and a conference of vice-presidents, District secretaries, and counselor delegates, ten technical sessions, one general session, and six conference sessions will be held. The general session designed to interest many members has been scheduled on Wednesday morning without parallel sessions in order to give all an opportunity to attend. The features of this session are addresses by President W. H. Harrison, Doctor W. R. Gregg, chief of the Weather Bureau, and Colonel J. M. Johnson, assistant secretary of commerce. At the annual meeting, on Tuesday morning, Colonel Dan I. Sultan, engineer commissioner, District of Columbia, will give an address.

ENTERTAINMENT

The summer convention committee requests that tickets be secured early for the entertainment features in order that proper reservations may be made. These include the following:

Tuesday, June 21

Luncheon bridge—tickets not later than Monday, 6:00 p.m.

Country club dinner dance—tickets not later than Tuesday noon.

Wednesday, June 22

Tea at Burgundy Farm—tickets not later than Wednesday, 10:00 a.m.

Thursday, June 23

Dinner, Mayflower Hotel—tickets not later than Thursday, 10:00 a.m.

REGISTRATION

Members who will attend the convention and who have not registered in advance are urged to do so promptly by returning the addressed advance registration card received by mail. This will be helpful to the committees and will permit badges to be made ready in advance, thus avoiding congestion at the registration desk. Please register promptly upon arrival at the convention.

A registration fee of $2.00 will be charged all nonmembers, except Enrolled Students, and the immediate families of members.

HOTEL RESERVATIONS

If you have not already made a hotel reservation, please do so, as the committee has urged that this be done well in advance. For a list of the principal hotels in Washington, D. C., and rates, as well as information regarding the Mayflower Hotel, convention headquarters, see ELECTRICAL ENGINEERING for May, pages 221 and 224.

RULES ON PRESENTING AND DISCUSSING PAPERS

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, ten minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is opened for general discussion. Usually five minutes is allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser should step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussions to be considered for

AIEE New York Section Visits Pittsfield, Mass.

CHAIRMAN Aram Boyajian (A'18, F'26) *left*, of the AIEE Pittsfield Section, shook hands with Chairman K. F. Bellows (A'30, M'38) of the power group of the New York Section on April 21, 1938, when nearly 200 members traveled by special train to Pittsfield to visit the plastics and transformer and capacitor plants of the General Electric Company. H. H. Barnes (A'00, F'13) commercial vice-president of the General Electric Company, New York, N. Y., may be seen to the left of Mr. Boyajian. High light of the trip was a demonstration of artificial lightning under the direction of K. B. McEachron (A'14, F'37, director). A 10,000,000-volt discharge of approximately 23,000 amperes jumping between electrodes 30 feet apart, splitting wood, and vaporizing wire, and a 1,000,000-volt three-phase 60-cycle colored arc between revolving pinwheels were shown.

Eastern Standard Time

Business and Technical Program of the Summer

Photo-offset copies of authors' manuscripts, exclusive of addresses, may be obtained in advance of the convention by writing to the AIEE Order Department, 33 West 39th Street, New York, N. Y. If ordered by mail, price 10c per copy; if purchased at Institute headquarters or at the convention, price 5c per copy. Coupon books in $1.00 and $5.00 denominations are available for those who wish to avoid remittance by check or otherwise. Most of the papers ultimately will be published in ELECTRICAL ENGINEERING or the TRANSACTIONS.

Monday, June 20

9:00 a.m.—Registration

10:00 a.m.—Conference of Officers, Delegates, and Members

11:00 a.m.—Separate Conferences

(*a*) Section delegates.
(*b*) Student Branch counselors.

2:00 p.m.—Conference of Officers, Delegates, and Members (continued)

Tuesday, June 21

9:30 a.m.—Annual Meeting

Address of welcome by Doctor William McClellan, honorary chairman.

Annual report of board of directors, in abstract, by H. H. Henline, national secretary.

Report of national treasurer.

Report of committee of tellers on (*a*) constitutional amendments, and (*b*) election of officers.

Introduction of and response from president-elect.

Presentation of Institute prizes for papers.

Presentation of Lamme Medal to Doctor R. E. Doherty.

Address: MUNICIPAL PLANNING IN WASHINGTON, **Colonel Dan I. Sultan,** engineer commissioner, District of Columbia.

2:00 p.m.—Power Transmission and Distribution

TRAVELING WAVES INITIATED BY SWITCHING, **L. V Bewley,** General Electric Company.

APPLICATION OF LARGE PHASE-SHIFTING TRANSFORMER ON AN INTERCONNECTED SYSTEM LOOP, **W. J. Lyman,** Duquesne Light Company, and **J. R. North,** Commonwealth and Southern Corporation.

TESTS ON OIL-IMPREGNATED PAPER—III—FLUID FLOW, **H. H. Race,** General Electric Company.

FIELD TESTING OF BUSHINGS AND TRANSFORMER INSULATION BY THE POWER FACTOR METHOD, **I. W. Gross,** American Gas and Electric Service Corporation.

FLASHOVER CHARACTERISTICS OF TRANSFORMER CONDENSER BUSHINGS, **H. L. Cole,** Westinghouse Electric and Manufacturing Company.

REACTANCE OF SQUARE TUBULAR BUSBARS, **H. B. Dwight** and **T. K. Wang,** Massachusetts Institute of Technology.

2:00 p.m.—Communication

ANALYSIS AND DESIGN OF HARMONIC GENERATORS, **F. E. Terman,** Stanford University.

A SYMBOLIC ANALYSIS OF RELAY AND SWITCHING CIRCUITS, **C. E. Shannon,** Massachusetts Institute of Technology.

INSTRUMENTS FOR THE NEW TELEPHONE SETS, **W. C. Jones,** Bell Telephone Laboratories, Inc.

TRANSMISSION FEATURES OF THE NEW TELEPHONE SETS, **A. H. Inglis,** Bell Telephone Laboratories, Inc.

Presentation by title:

TRANSMISSION THEORY OF SPHERICAL WAVES, **S. A. Schelkunoff,** Bell Telephone Laboratories, Inc.

2:00 p.m.—Symposium on Correlation of Mathematics and Physics With Electrical Engineering Subjects

THE CO-ORDINATION OF MATHEMATICS AND PHYSICS WITH ELECTRICAL ENGINEERING SUBJECTS, **W. A. Curry,** Columbia University.

A COURSE TO DEVELOP FACILITY IN THE USE OF MATHEMATICS AND PHYSICS IN THE SOLUTION OF ENGINEERING PROBLEMS, **B. R. Teare, Jr.,** Yale University.

CO-ORDINATION OF PHYSICS WITH ELECTRICAL ENGINEERING, **J. M. Bryant,** University of Minnesota.

CO-ORDINATION OF MATHEMATICS AND PHYSICS WITH ELECTRICAL ENGINEERING SUBJECTS, **T. H. Morgan,** Worcester Polytechnic Institute.

MATHEMATICS AND PHYSICS IN ENGINEERING, **M. G. Malti,** Cornell University.

2:00 p.m.—Conference on Machines in Mathematical Analysis

Wednesday, June 22

9:30 a.m.—General Session

(President W. H. Harrison, presiding)

Address of the president.

Address: PROGRESS IN WEATHER FORECASTING, **Doctor W. R. Gregg,** chief of the Weather Bureau.

Address: THE PRESENT AND FUTURE OF COMMERCIAL AVIATION, **Colonel J. M. Johnson,** assistant secretary of commerce.

Thursday, June 23

9:30 a.m.—Fault Interruption—I

THE CURRENT-LIMITING POWER FUSE, **D. C. Prince** and **E. A. Williams, Jr.,** General Electric Company.

A NEW MULTI-BREAK INTERRUPTER FOR FAST-CLEARING OIL CIRCUIT BREAKERS, **R. M. Spurck** and **H. E. Strang,** General Electric Company.

TESTS ON AND PERFORMANCE OF A HIGH-SPEED MULTI-BREAK 138-KV OIL CIRCUIT BREAKER, **Philip Sporn** and **H. P. St. Clair,** American Gas and Electric Service Corporation.

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publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th St., New York, N. Y., on or before July 8, 1938.

Thomson Papers Being Collected

Because of his long period of membership and interest in the American Philosophical Society, the many papers, manuscript and printed, accumulated by the late Doctor Elihu Thomson are being collected and will be housed permanently by the society. Doctor Thomson was a charter member of the AIEE and its fifth president (1889–90); he was elected an Honorary Member in 1928. According to a recent announcement, the society already has collected about 2,000 pieces of correspondence, five volumes of Doctor Thomson's manuscript comments on his numerous patents, an almost complete set of his many articles contributed to scientific periodicals, a number of letter-books containing his correspondence during the early days of the General Electric Company and its forerunners, and other miscellaneous items.

In order to make the collection as complete as possible, the society has asked the many organizations of which Doctor Thomson was a member to notify their memberships of this project in the hope that thereby many scattered pieces of Thomsoniana might be added to the collection. The society will be very glad to accept copies of material with which original owners may be loath to part. The American Philosophical Society may be addressed at 222 Drexel Building, Philadelphia, Pa.

The General Electric Company also has announced that the office Doctor Thomson occupied for nearly 30 years in the old administration building of the company's West Lynn (Mass.) Works will be maintained as a museum containing historical material associated with his career. Among other things, the company plans to exhibit in this museum models of many of his numerous inventions.

Pacific Coast Program Nearing Completion

General arrangements for the 1938 AIEE Pacific Coast convention to be held in Portland, Ore., are now practically complete, according to General Chairman E. F. Pearson. The Multnomah Hotel has been selected as convention headquarters. As previously announced, the dates for this convention, August 9–12, have been selected to encourage members and their friends to combine their vacation trips with attendance at the convention. At this time the scenic beauty of Oregon is usually at

Convention, Washington, D. C., June 20–24

Eastern Standard Time

DRION AIR CIRCUIT BREAKERS FOR A-C FEEDER, MOTOR STARTING AND STATION AUXILIARY SERVICE, **R. C. Dickinson**, Westinghouse Electric and Manufacturing Company.

ENCLOSED LOW-VOLTAGE DRION AIR CIRCUIT BREAKER OF HIGH INTERRUPTING CAPACITY, **Jerome Sandia**, Westinghouse Electric and Manufacturing Company.

9:30 a.m.—Electrical Machinery

DOUBLE LINE-TO-NEUTRAL SHORT CIRCUIT OF AN ALTERNATOR, **James B. Smith**, Factory Mutual Fire Insurance Company, and **C. N. Weygandt**, University of Pennsylvania.
EE, September 1937, pages 1149–55

AN ANALYSIS OF THE INDUCTION MACHINE, **H. C. Stanley**, American Gas and Electric Service Corporation.

AMPLITUDES OF THE MAGNETOMOTIVE-FORCE HARMONICS FOR FRACTIONAL SLOT WINDINGS—I, **J. F. Calvert**, Iowa State College.

THE CAUSE AND ELIMINATION OF NOISE IN SMALL MOTORS, **W. R. Appleman**, Marathon Electric Manufacturing Corporation.
EE, November 1937, pages 1359–67

THE WOUND-CORE DISTRIBUTION TRANSFORMER, **E. D. Treanor**, General Electric Company.

9:30 a.m.—Selected Subjects

THE ECONOMIC STATUS OF THE ENGINEER, **R. W. Sorensen**, California Institute of Technology.

A SELF-CHECKING SYSTEM OF SUPERVISORY CONTROL, **M. E. Reagan**, Westinghouse Electric and Manufacturing Company.

APPLICATION OF CAPACITANCE POTENTIAL DEVICES, **J. E. Clem**, General Electric Company.

RADIO INFLUENCE CHARACTERISTICS OF ELECTRICAL APPARATUS, **P. L. Bellaschi** and **C. V. Aggers**, Westinghouse Electric and Manufacturing Company.

NOISE CO-ORDINATION OF RURAL POWER AND TELEPHONE SYSTEMS, **H. W. Wahlquist**, Edison Electric Institute, and **T. A. Taylor**, Bell Telephone Laboratories, Inc.

9:30 a.m.—Electronics and Basic Sciences

POSITIVE-GRID CHARACTERISTICS OF TRIODES, **R. W. Porter**, General Electric Company.

A POSITION REGULATOR FOR PAPER SLITTERS, **F. H. Gulliksen**, Westinghouse Electric and Manufacturing Company.

COMBINED THYRATRON AND TACHOMETER SPEED CONTROL OF SMALL MOTORS, **A. J. Williams, Jr.**, Leeds and Northrup Company.

A STATIC CONSTANT-CURRENT CIRCUIT, **C. M. Summers**, General Electric Company.

Presentations by title:

GRAPHICAL FIELD PLOTTING METHODS IN ENGINEERING, **Hillel Poritsky**, General Electric Company.

BASIC EQUATIONS FOR ELECTRIC AND SOUND RADIATIONS, **L. Alan Hazeltine**, Stevens Institute of Technology.

12:30 p.m.—Board of Directors' Luncheon Meeting—Mayflower Hotel

3:00 p.m.—Conference of Vice-Presidents, District Secretaries, and Counselor Delegates

2:00 p.m.—Conference Sessions:

(*a*) Modernization of power plants.
(*b*) Electrical machinery.
(*c*) Electronics.
(*d*) Conference on definitions.

Friday, June 24

9:30 a.m.—Symposium on Fluorescent Lighting

THE FUNDAMENTAL PRINCIPLES OF FLUORESCENCE, **G. R. Fonda**, General Electric Company.

LOW-VOLTAGE FLUORESCENT LAMPS, **G. E. Inman** and **R. N. Thayer**, General Electric Company.

HIGH-VOLTAGE ADVERTISING AND DECORATIVE TUBE LIGHTING, **J. A. McDermott**, Claude Neon Lights, Inc.

Demonstration Lecture: PENNY WISE POUND FOOLISH—HOW TO GET THE MOST FOR YOUR LIGHTING DOLLAR, **A. L. Powell**, General Electric Company.

9:30 a.m.—Fault Interruption—II and Lightning Protection

REMOTE CONTROL OF NETWORK PROTECTORS, **W. R. Brownlee** and **W. E. Dent, Jr.**, Tennessee Electric Power Company.

SYSTEM ANALYSIS FOR PETERSEN COIL APPLICATION—PART I. OPERATING FEATURES AND BASIC CALCULATIONS—PART II. SYSTEM ANALYSIS AND COMPUTATIONS, **W. C. Champe** and **F. von Voigtlander**, The Commonwealth and Southern Corporation.

LIGHTNING PROTECTION OF 22-KV SUBSTATIONS, **E. R. Whitehead**, Duquesne Light Company.

LINE-TYPE LIGHTNING-ARRESTER PERFORMANCE DATA, Lightning arrester subcommittee.

9:30 a.m.—Instruments and Measurements

A MEMORY ATTACHMENT FOR OSCILLOSCOPES, **W. E. Pakala**, Westinghouse Electric and Manufacturing Company.

ABSOLUTE POWER FACTOR OF AIR CAPACITORS, **W. B. Kouwenhoven** and **E. L. Lotz**, The Johns Hopkins University.

THE ELECTRIC STRAIN GAUGE, **M. A. Rusher** and **A. V. Mershon**, General Electric Company.

9:30 a.m.—Conference on Power Requirements in Electrochemical and Allied Industries

Address: POWER REQUIREMENTS IN THE ELECTROCHEMICAL, ELECTROMETALLURGICAL, AND ALLIED INDUSTRIES, **A. V. Alfriend, Jr.**, Federal Power Commission.

Discussion by: **M. E. Stone**, United Engineering and Foundry Company, Ltd.; **E. G. Merrick**, General Electric Company; **Herbert Speight**, Westinghouse Electric and Manufacturing Company.

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its best. Details of the program will be announced in the July issue.

Several excellent inspection trips have been arranged, including one to the Bonneville hydroelectric development, which will be completed prior to the convention, and another to the new Timberline Lodge on Mount Hood. The annual golf tournament will be played on Oswego Lake Country Club course, which is considered one of the finest of the Northwest.

Student Conference Held by North Central District

The 11th annual conference of Student Branches of the AIEE North Central District, held at the University of Nebraska, Lincoln, April 22–23, attracted 123 students in electrical engineering, AIEE Section and District officers, and guests. Three guests from Kansas State College, Manhattan (AIEE South West District) were registered and representatives were sent from all of the nine Branches in the district:

Colorado State College of Agriculture and Mechanic Arts, Fort Collins.
University of Colorado, Boulder.
University of Denver, Denver, Colo.
North Dakota State College, Fargo.
University of North Dakota, Grand Forks.
South Dakota State College, Brookings.
South Dakota State School of Mines, Rapid City.
University of Wyoming, Laramie.
University of Nebraska, Lincoln.

With B. J. Dalton, chairman of the University of Nebraska Branch, presiding, the morning session on April 22 was opened with an address of welcome by O. J. Ferguson (A'05, F'13) dean of the college of engineering of the University of Nebraska. L. N. McClellan (A'14, M'26) chief electrical engineer of the United States Bureau of Reclamation, Denver, Colo., and vice-president of the AIEE made an appropriate response.

After Mr. McClellan's talk the first technical session was convened with Eugene Jackson, chairman of the South Dakota State College Branch, presiding. The following papers were presented:

THEORY AND APPLICATION OF THE THYRATRON-CONTROLLED STROBOSCOPE, **M. E. Mohr**, University of Nebraska.

HYPER-FREQUENCY WAVE GUIDES, **Eugene McFall**, University of Colorado.

ELECTROMECHANICAL RECORDING AND REPRODUCTION OF SOUND BY THE DISK METHOD, **Elmer W. Everson**, University of North Dakota.

Following discussion of the papers, I. M. Ellestad (A'24) transmission engineer of the Northwestern Bell Telephone Company, Omaha, Nebr., delivered an address entitled "Application of Newly Developed Cold-Cathode Discharge Tube to Telephone and Industrial Control."

With R. H. Payne, chairman of the Colorado State College Branch, presiding, the following papers were presented and discussed at the afternoon technical session:

THE ELECTROLYTIC CONDENSER AND ITS DEVELOPMENT, **Carl Cadwell**, University of Wyoming.

THE USES OF ELECTRICITY IN MEDICAL QUACKERY, John Herron, South Dakota State College.

THE EFFICIENCY OF SMALL ELECTRIC MOTORS, John L. C. Lof, University of Denver.

Elmer Maul, chairman of the University of Colorado Branch, presided over the third technical session, at which the following papers were presented and discussed:

THE PIEZOELECTRIC EFFECT, William Kossila, North Dakota State College.

AUTOMOBILE HEAD LIGHTING AS IT IS AND AS IT MIGHT BE, J. C. Smith, South Dakota State School of Mines.

At the convention banquet, held on Friday evening, the principal address was delivered by R. M. Armstrong, of the Nebraska Unicameral Legislature. John L. C. Lof, of the University of Denver, won first prize for his paper and honorable mention was given to the paper by M. E. Mohr, of the University of Nebraska.

Following the banquet a business session of the Student Branch counselors was held. The University of Wyoming, Laramie, was selected as the site of the next Branch conference, with the dates established as April 21–22, 1939.

North West District Executive Committee Meets

The annual meeting of the executive committee of the Institute's North West District was held at Seattle, Washington, on April 19, 1938. The following members were present:

C. E. Rogers, vice-president, AIEE, presiding
S. E. Caldwell, secretary, North West District
W. A. Boyer, vice-chairman, Montana Section
C. C. Boozier, chairman, Portland Section
C. H. Hoge, chairman, Seattle Section
M. F. Hatch, chairman, Spokane Section
C. A. Wolfrom, chairman, Utah Section
A. L. Taylor, chairman, District committee on student activities, University of Utah, Salt Lake City
John Bankus, vice-chairman, national membership committee
L. R. Gamble of Spokane, nominee for vice-president, was present by invitation

Section reports indicated a very active interest in Institute activities throughout the District. The co-operation between Sections of the North West and Pacific Districts in arranging program schedules to fit itineraries of visiting engineers has made it possible for the Sections to have some exceedingly interesting and well attended meetings. Technical groups organized in the Portland and Seattle Sections have proved a material help in stimulating interest and getting new members. The group meetings have provided an excellent place for the interchange of ideas and a greater opportunity for the younger members to take part in Section activities. Vice-President Rogers pointed out that each Section could employ this idea to greater advantage by organizing additional technical groups in the larger outlying communities of its territory and thereby stimulate and hold the interest of members that would otherwise not be able to participate in any Section activities.

The District has shown a substantial increase in membership during the past year. Some of the Section membership committees obtained good results from return postal cards sent out to members requesting names of prospects. Members who had been dropped because of delinquent dues were, in a number of cases, induced to rejoin by paying back dues during the current year, for which limited Section privileges were accorded, and then to submit their application for reinstatement at the beginning of the next fiscal year. The suggestion was made that a faculty member from each college having a Student Branch, preferably the counselor, should be a member of his Section's membership committee in order to maintain closer contact with student members eligible for transfer to associate grade.

C. C. Boozier, chairman of the Portland Section, reported that the plans for the 1938 Pacific Coast convention to be held in Portland, Ore., August 9–12 were 100 per cent complete, that a full program of technical papers, inspection and scenic trips, sports, and entertainment had been planned, and that the date had been advanced to early in August in order that all who might desire could plan their vacation to coincide with the convention.

A resolution was adopted by the District executive committee expressing, upon behalf of the membership, its deepest regret over the death of Professor Thaler and its most sincere appreciation of his long and continued service and contributions to the Institute's activities and a copy of the resolution was transmitted to Professor Thaler's family.

At the close of the meeting the members of the committee extended to Vice-President Rogers a vote of appreciation for his active interest, counsel, and assistance during the past two years and for his efforts in procuring outstanding engineers as speakers for the Sections.

AIEE National Prize Awards Announced for 1937 Papers

THE committee on award of Institute prizes has announced the award of three national prizes for papers presented during the calendar year 1937. In two classifications, because of the small number of eligible papers, no awards were made. Presentation of the prizes will be made during the AIEE summer convention at Washington, D. C., June 20–24, 1938. The committee consists of H. S. Osborne (A'10, F'21) *chairman*, J. W. Barker (M'26, F'30) W. B. Kouwenhoven (A'06, F'34) and I. Melville Stein (A'18, M'27).

Rules governing the award of prizes were published in ELECTRICAL ENGINEERING for April 1937, page 492. The following awards of national prizes for 1937 papers were made after consideration of all the eligible papers:

BEST PAPERS

Best Paper in Engineering Practice. This prize was awarded to J. W. Dawson (M'35) for his paper "New Developments in Ignitron Welding Control," published in ELECTRICAL ENGINEERING for December 1936, pages 1371–8, and discussed at the winter convention, New York, N. Y., January 25–29, 1937.

Honorable mention was made of the following papers: "Approximating Potier Reactance" by Sterling Beckwith (A'34) discussed at the summer convention, Milwaukee, Wis., June 21–25, 1937, and published in ELECTRICAL ENGINEERING for July 1937, pages 813–18; "Development of a Modern Watt-Hour Meter" by I. F. Kinnard (A'21, M'28) and H. B. Trekell (A'35) published in ELECTRICAL ENGINEERING for January 1937, pages 172–9, and discussed at the winter convention, New York, N. Y., January 25–29, 1937; "Switchboards for Boulder Power Plant" by L. N. McClellan (A'14, M'26) A. J. A. Peterson (A'16, M'30) and C. P. Garman (A'23, M'26) published in ELECTRICAL ENGINEERING for February 1937, pages 224–36, and discussed at the summer convention, Milwaukee, Wis., June 21–25, 1937; and "System Recovery Voltage Determination by Analytical and A-C Calculating Board Methods," by R. D. Evans (A'21, M'26) and A. C. Monteith (A'25) published in ELECTRICAL ENGINEERING for June 1937, pages 695–705, and discussed at the summer convention, Milwaukee, Wis., June 21–25, 1937.

Best Paper in Theory and Research. This prize was awarded to C. L. Dawes (A'12, F'35) and Reuben Reiter (A'36) for their paper "Electrical Characteristics of Suspension-Insulator Units," published in ELECTRICAL ENGINEERING for January 1937, pages 59–66, and discussed at the summer convention, Milwaukee, Wis., June 21–25, 1937.

Honorable mention was made of the following papers: "Dyadic Algebra Applied to Three-Phase Circuits," by A. P. T. Salt (A'35, M'36) published in ELECTRICAL ENGINEERING for August 1936, pages 876–82, and discussed at the winter convention, New York, N. Y., January 25–29, 1937; "Magnetic Generation of a Group of Harmonics," by Eugene Peterson (M'26), J. M. Manley and L. R. Wrathall, published in ELECTRICAL ENGINEERING for August 1937, pages 995–1001, and discussed at the Pacific Coast convention, Spokane, Wash., August 30–September 3, 1937; "Properties of Saturants for Paper-Insulated Cables," by G. M. L. Sommerman (A'31, M'37) published in ELECTRICAL ENGINEERING for May 1937, pages 566–76, and discussed at the summer convention, Milwaukee, Wis., June 21–25, 1937; and "Short-Time Spark-Over of Gaps," by J. H. Hagenguth (A'28) published in ELECTRICAL ENGINEERING for January 1937, pages 67–76, and discussed at the winter convention, New York, N. Y., January 25–29, 1937.

Best Paper in Public Relations and Education. Because only one paper in this classification was presented during the year, the committee made no award, and this paper, together with two papers in this classification from 1936, will be held over for consideration for a future award in this classification.

INITIAL PAPER

Prize for initial paper was awarded to H. R. Reed (A'28, M'34) and R. J. W. Koopman (A'36) for their paper "Induction Motors on Unbalanced Voltages," published in ELECTRICAL ENGINEERING for November 1936, pages 1206–13, and discussed at the winter convention, New York, N. Y., January 25–29, 1937.

Honorable mention was made of the following papers: "A Review of Overhead Secondary Distribution," by W. P. Holben (A'20, M'27), published in ELECTRICAL ENGINEERING for January 1937, pages 114–22 and 189, and discussed at the winter convention, New York, N. Y., January 25–29, 1937; and "Fundamental Concepts of Synchronous-Machine Reactances," by B. R. Prentice (A'35), presented at the summer convention, Milwaukee, Wis., June 21–25, 1937, and published in AIEE TRANSACTIONS, volume 56, 1937, pages 1–21 of Supplement.

BRANCH PAPER

Only three papers eligible for this award were submitted for consideration, and therfore no award was made this year. The committee points out that an inadequate group of papers was submitted

despite the fact that more than 1,100 student talks were presented at Branch meetings during the year.

District prize awards for 1937 papers will be announced in future issues as this information is made available.

Dates Selected for Southern District Meeting

November 28–30 has been chosen as the time for the AIEE Southern District meeting to be held this year at Miami, Fla. This is one of the actions taken by the District meeting committee when it met April 21 in Jacksonville to discuss preliminary plans.

Headquarters for the meeting will be at the Miami Biltmore Hotel. In addition to ample facilities for all convention activities, the hotel and its grounds include an 18-hole golf course, swimming pool, tennis courts, and other recreational facilities, as well as access to beach and fishing accommodations.

1938 Washington Award Presented to F. B. Jewett

For "inspiring and directing scientific research leading to improvements in the art of communication," the Washington Award for 1938 was presented to F. B. Jewett (A'03, F'12, past-president) at Chicago, Ill., on May 5, 1938, by L. R. Howson, president of the Western Society of Engineers, at a dinner held by the Washington Award Commission. Announcement of the selection of Doctor Jewett as 1938 recipient and a brief history of the award, which is given by a commission composed of representatives of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, AIEE, and Western Society of Engineers, were published in ELECTRICAL ENGINEERING for February 1938, pages 78–9.

Following the presentation ceremony, Doctor Jewett delivered an address on "The Engineer and Current Trends in Economic Thought." C. H. MacDowell, chairman of the commission, presided.

Future AIEE Meetings

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., August 9–12, 1938

Southern District Meeting
Miami, Fla., November 28–30, 1938

Winter Convention
New York, N. Y., January 23–27, 1939

South West District Meeting
Houston, Texas, Spring, 1939

Section and Branch Activities

Annual Report for 1937–38

THE following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1938. Similar information for three preceding fiscal years appeared in ELECTRICAL ENGINEERING for June 1937, pages 762–5; June 1936, pages 752–4; and June 1935, pages 674–5.

The names of present members of the Sections committee and the committee on Student Branches, which supervise these two important divisions of Institute activities covered by this report, are: Sections—W. H. Timbie, *chairman*, M. S. Coover, W. M. Dann, O. W. Holden, E. T. Mahood, H. H. Race, I. M. Stein, C. S. Thorn, and, *ex-officio*, the chairmen of all Sections of the Institute. Student Branches—F. Ellis Johnson, *chairman*, Edward Bennett, E. E. Dreese, O. E. Edison, O. W.

Table I. Section Meetings Held During Year Ending April 30, 1938

Section	AIEE Members August 1936	AIEE Members August 1937	Meetings During Year Number	Meetings During Year Average Attendance	Meetings During Year Average Attendance as Per Cent of Membership, August 1937
Akron	67	63	8	68	108
Alabama	42	48	5	137	285
Baltimore	174	188	8	137	73
Boston	386	409	8	401	98
Central Indiana	116	135	7	127	94
Chicago	603	674	11	265	39
Power group			5	149	
Industrial group			3	93	
Cincinnati	159	175	10	136	78
Cleveland	245	285	8	166	58
Motors and control group			3	46	
Electronics group			2	53	
Columbus	63	79	5	50	63
Connecticut	267	266	9	390	147
Dallas	89	101	10	177	176
Denver	132	160	7	263	164
Detroit-Ann Arbor	320	353	9	577	163
East Tennessee	49	76	9	110	145
Erie	52	63	7	192	305
Florida	60	66	3	80	121
Fort Wayne	64	86	9	77	90
Georgia	72	83	10	136	164
Houston	75	89	12	140	157
Iowa	56	53	7	105	198
Ithaca	54	54	10	51	94
Kansas City	148	122	9	125	102
Lehigh Valley	184	197	9	176	89
Los Angeles	440	470	10	434	92
Louisville	50	49	8	93	190
Lynn	120	128	11	518	405
Technical lectures			5	290	
Madison	48	64	11	155	242
Memphis	33	53	11	47	89
Mexico	67	67	7	42	63
Milwaukee	208	268	11	211	79
Minnesota	72	88	6	73	83
Power committee			3	39	
Montana	38	39	8	215	551
Muscle Shoals*		33	7	156	473
Nebraska	56	55	8	63	115
New Orleans	50	64	8	81	127
New York	3,036	3,308	4	563	17
Power group			7	281	
Communication group			5	314	
Transportation group			3	133	
Illumination group			4	506	
Electrophysics group			2	325	
Niagara Frontier	208	218	8	307	141
North Carolina	83	77	3	96	125
Oklahoma City	120	97	9	113	116
Philadelphia	550	571	8	191	33
Pittsburgh	411	464	8	224	48
Pittsfield	121	150	11	855	570
Colloquium series			4	42	
Portland	110	119	11	195	164
Transmission and distribution committee			6	30	
Communication committee			4	22	
Providence	82	93	7	83	89
Rochester	80	92	15	116	126
Communication group			2	9	
Power group			2	23	
St. Louis	201	240	8	239	100
San Antonio	29	35	7	40	114
San Francisco	401	442	8	205	46
Special technical meetings			7	373	
Saskatchewan	25	25	9	48	192
Schenectady	367	397	9	319	80
Technical discussion meetings			4		
Seattle	146	144	11	199	138
Power group			5	42	
Communication and electronics technical group			5	61	
Sharon	62	77	9	79	103
Spokane	48	55	8	265	482
Springfield	68	68	9	91	134
Syracuse	71	73	3	230	315
Toledo	66	78	8	120	154
Toronto	293	309	13	151	49
Discussion group			1	111	
Tulsa†		61	6	132	216
Urbana	36	58	5	232	400
Utah	41	59	9	198	336
Vancouver	97	99	12	53	54
Virginia	90	92	2	60	65
Washington	258	256	8	137	54
Special technical meeting			1	108	
Wichita‡		27	9	30	111
Worcester	63	67	8	92	137
Total	65	11,822	13,054		
Total number of meetings					624
Total attendance					110,148

* Organized February 18, 1938—previously power group, Alabama Section.
† Organized September 16, 1937.
‡ Organized October 18, 1937.

Table II. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1936	1937	1938
Number of Sections	61	62	65
Number of meetings held	540	621	624
Average number of meetings	8.9	10.0	9.6
Total attendance	85,501	74,950	110,148
Average attendance per meeting	158	121	177

Eshbach, T. W. Fitzgerald, E. A. Loew, Charles F. Scott, R. W. Sorensen, and, *ex officio*, all Student Branch counselors.

Section Activities

Three new Sections were organized during the year: Wichita in September, Tulsa in October, and Muscle Shoals in February. These brought the total number of Sections to 65, and each of the new Sections carried on normal amounts of activity. The name of the Atlanta Section was changed to "Georgia Section," and it was granted the entire state as its territory.

The total number of Section meetings reported was 624, as compared with 621 for the preceding year, which had far exceeded the number for any previous year. Many Sections continued to show keen interest in technical groups, special technical meetings, technical committees, etc.

President Harrison visited nearly 30 Sections, and his addresses were deeply appreciated. He will visit a few others in May and June.

One of the outstanding features of Section activities was a lecture-demonstration showing the application of scientific knowledge to modern communication given by Doctor J. O. Perrine, associate editor, *Bell System Technical Journal*, at meetings of nearly one-third of the Sections, with an average attendance of more than 1,000.

The New York Section organized an electrophysics group, and the activities of the other four groups were continued.

An investigation made by the Washington Section indicated sufficient interest to justify holding certain meetings of a more technical type. The executive committee authorized two such meetings, and the first, on electronics, was held on February 23 with an attendance of 108.

The Connecticut Section sent postal cards to its members in October requesting expressions of their choices among several groups of subjects and indications of their preferences as to type of treatment: highly technical, moderately technical, or descriptive.

The Schenectady Section distributed a questionnaire, in November, inviting its members to choose 5 subjects for technical discussion meetings from a list of 15 mentioned, and left a blank for other subjects.

The New Orleans Section had an interesting meeting devoted to a round table discussion of topics selected from Electrical Engineering.

The Pittsfield Section devoted a meeting of its colloquium series to discussion of eight papers presented at the 1938 winter convention.

The Lynn Section held two local conventions, one for technical-papers competition, and the other for popular-papers competition. The prizes in each case were $15, $10, and $5.

In order to secure the views of its mem-

Table III. Branch Meetings Held During Year Ending April 30, 1937

Branch	Meetings During Year: Number	Average Attendance	Approximate Number of Talks by Students
Akron, University of	8	17	
Alabama Polytechnic Institute	12	64	5
Alabama, University of	18	16	4
Arizona, University of	28	11	18
Arkansas, University of	18	37	15
Armour Institute of Technology	13	41	8
British Columbia, University of	15	29	16
Brooklyn, Polytechnic Institute of	10	51	4
Brown University	12	37	3
Bucknell University	14	13	7
California Institute of Technology	13	24	3
California, University of	18	62	
Carnegie Institute of Technology	31	45	25
Case School of Applied Science	26	55	21
Catholic University of America	5	10	4
Cincinnati, University of	6	37	7
Clarkson College of Technology	13	149	1
Clemson Agricultural College	5	28	9
Colorado State Agricultural College	5	13	5
Colorado, University of	11	55	10
Columbia University	3	22	1
Cooper Union			
Day division	12	24	7
Evening division	5	12	1
Cornell University	3	17	
Denver, University of	14	42	1
Detroit, University of	7	31	
Drexel Institute	21	33	4
Duke University	9	26	11
Florida, University of	13	28	7
George Washington University	7	28	3
Georgia School of Technology	5	46	
Harvard University	3	28	
Idaho, University of	10	39	3
Illinois, University of	11	141	
Iowa State College	16	84	3
Iowa, University of	22	51	19
Johns Hopkins University	17	24	13
Kansas State College	20	134	36
Kansas, University of	9	125	3
Kentucky, University of	15	80	4
Lafayette College	6	20	4
Lehigh University	3	75	
Lewis Institute	13	35	
Louisiana State University	17	22	6
Louisville, University of			
Maine, University of	6	21	5
Marquette University	9	39	1
Maryland, University of	10	29	12
Massachusetts Institute of Technology	10	76	3
Michigan College of Mining & Technology	12	42	9
Michigan State College	16	35	7
Michigan, University of	8	64	3
Milwaukee School of Engineering	8	48	1
Minnesota, University of	12	63	7
Mississippi State College	9	35	4
Missouri School of Mines & Metallurgy	9	38	7
Missouri, University of	10	60	3
Montana State College	25	28	54
Nebraska, University of	15	49	10
Nevada, University of	9	31	
Newark College of Engineering	7	36	9
New Hampshire, University of	10	48	
New Mexico, University of	5	14	3
New York, College of the City of			
Day division	17	71	3
Evening division	5	11	1
New York University			
Day division	4	19	1
Evening division			
North Carolina State College	16	32	9
North Carolina, University of	6	10	7
North Dakota State College	7	13	2
North Dakota, University of	14	13	8
Northeastern University	13	51	
Northwestern University*	8	31	8
Notre Dame, University of	1	37	1
Ohio Northern University	8		9
Ohio State University	11	42	7
Ohio University	13	17	5
Oklahoma A. & M. College	11	40	12
Oklahoma, University of	9	40	10
Oregon State College	12	159	
Pennsylvania State College	9	34	
Pennsylvania, University of	2	17	
Pittsburgh, University of	24	84	17
Porto Rico, University of			
Pratt Institute	22	43	8
Princeton University	6	60	3
Purdue University	12	237	6
Rensselaer Polytechnic Institute	6	128	6
Rhode Island State College	10	38	2
Rice Institute	14	19	7
Rose Polytechnic Institute	5	29	5
Rutgers University	6	28	
Santa Clara, University of	11	18	10
South Carolina, University of	8	9	1
South Dakota State College	13	19	9
South Dakota State School of Mines	7	24	3
Southern California, University of	12	18	8
Southern Methodist University	7	30	8
Stanford University	7	26	
Stevens Institute of Technology	5	12	
Swarthmore College	2	56	
Syracuse University	33	59	12
Tennessee, University of	8	100	1
Texas A. & M. College	12	68	5
Texas Technological College	14	18	3
Texas, University of	3	21	4
Tufts College	5	24	1
Tulane University	5	30	8
Union College	7	36	3
Utah, University of	9	22	12
Vermont, University of	18	15	10
Villanova College	11	26	15
Virginia Military Institute	14	35	10
Virginia Polytechnic Institute	24	54	34
Virginia, University of	6	19	4
Washington, State College of	11	38	5
Washington, University of	11	62	9
Washington University	11	46	
West Virginia University	19	38	143
Wisconsin, University of	6	37	
Worcester Polytechnic Institute	3	35	5
Wyoming, University of	17	11	4
Yale University	12	21	4
Total	120		897
Total number of meetings			1,334
Total attendance			60,446

*Authorized by board of directors January 26, 1937, organized November 11, 1937.

Table IV. Branch Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1936	1937	1938
Number of Branches	118	119	120
Number of meetings held	1,045	1,363	1,334
Average number of meetings	8.9	11.5	11.1
Total attendance	45,304	46,121	60,446
Average attendance per meeting	43	33.8	45.3
Number of student talks	772	1,130	897

Table V. Conferences on Student Activities

District or Section	Location	Date
1	Buffalo, N. Y. (North Eastern District meeting)	5/7/37
2	Akron, Ohio (Middle Eastern District meeting)	10/15/37
8 & 9, University of British Columbia	Spokane, Wash. (Pacific Coast convention)	9/1/37
4	Virginia Military Institute, Lexington	3/25/38
5	University of Illinois, Urbana	4/22/38
6	University of Nebraska, Lincoln	4/22/38

Table VI. Student Conventions

Sponsored by District, Section, or Branch	Location	Date	Number of Student Papers
1	Buffalo, N. Y. (North Eastern District meeting)	5/7/37	8
8 & 9, University of British Columbia	Spokane, Wash. (Pacific Coast convention)	9/1–2/37	11
2	Akron, Ohio (Middle Eastern District meeting)	10/15/37	6
4	Virginia Military Institute, Lexington	3/25/38	6
Lehigh University	Lehigh University Bethlehem, Pa.	4/11/38	
University of Illinois	Urbana	4/23/38	4
6	University of Nebraska, Lincoln	4/22/38	8
New York Section	Newark College of Engineering, Newark, N. J.	4/28/38	5

bers on types of programs, papers, etc., the Houston Section had several brief talks on topics previously assigned given at a meeting in September. The announcement of its January meeting contained a request that members advise the secretary or chairman of their interest in any additional activities such as several which were mentioned.

The Cincinnati Section organized a study discussion group for consideration of social problems in which engineers should be of greater service. The earlier meetings were devoted to discussion of articles on social and economic subjects which recently appeared in ELECTRICAL ENGINEERING.

The Connecticut Section sent a questionnaire to its members in the fall to ascertain their preferences regarding types of educational courses. A course in electronics was given. The power group of the New York Section gave courses in electrical engineering and public speaking in the fall, and repeated them in the spring. The power group and the ASME metropolitan section gave courses in structural planning and design and engineering economics and practice in the fall, and again in the spring. The communication group of the New York Section gave a course in electronics. The Vancouver Section gave a course in electrical theory and engineering practice.

The Pittsfield and Schenectady Sections held their ninth annual competition in two joint meetings, one in each city, with three speakers representing each Section at each meeting. Prizes of $15 and $10 were awarded at each meeting.

The Seattle and Springfield Sections each held a prize-paper meeting with a prize of $25 for the best paper. The Portland Section held its annual competition with prizes of $15 and $10. Eight papers were presented. The power group of the New York Section held a volunteer-paper contest with prizes of $50 and $25.

The Sections which have been sponsoring student activities through the holding of joint meetings with Branches, or student conventions, continued the arrangements, with the usual keen interest and appreciation on the part of the students. Detailed information on such activities is given in table VII.

Table I contains tabular information on the meetings of all Sections and of their technical groups, technical committees, discussion groups, and other subdivisions.

Table II contains numerical information on Section meetings held during the past three fiscal years.

BRANCH ACTIVITIES

A new Branch organized at Northwestern University brought the total number to 120. A large majority of the Branches carried on normal amounts of activity. The total number of meetings reported was slightly below that for the preceding fiscal year, but was far larger than the total for any other year. The total number of student talks was below that for the preceding year, but larger than the totals for the fiscal years ending in 1935 and 1936, and smaller than the totals for the previous four years.

During the past fiscal year, 23 Branches held more than 15 meetings each, 59 held from 8 to 15, 27 held from 4 to 7, and 11 held fewer than 4 meetings.

Students continued their usual enthusiastic participation in national conventions and District meetings, and student sessions

Table VII. Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Schools	Date	Student Talks	Attendance
Cincinnati	University of Cincinnati	5/4/37	7	125
Oklahoma City	Oklahoma A. & M. College, University of Oklahoma	5/14/37	6	112
Portland	Oregon State College	5/15/37	3	90
St. Louis	Missouri School of Mines & Met., University of Missouri, Washington University	5/21/37	6	85
Utah	University of Utah	5/24/37	3	50
Pittsburgh	Carnegie Institute of Technology, Pennsylvania State College, University of Pittsburgh, West Virginia University	1/11/38	3	285
Dallas	Southern Methodist University	1/26/38	4	105
Kansas City	University of Kansas	2/15/38	2	75
Vancouver	University of British Columbia	3/7/38	3	52
Philadelphia	Drexel Institute, University of Pennsylvania, Swarthmore College, Villanova College	3/15/38	4	125
Houston	Rice Institute, Texas A. & M. College	3/18/38	2	48
Iowa	Iowa State College, University of Iowa	4/5/38	9	109
Chicago	Armour Institute of Technology, Lewis Institute, Northwestern University	4/6/38	5	100
Washington	Catholic University of America, George Washington University, University of Maryland	4/12/38	3	70
Spokane	University of Idaho, Washington State College	4/15/38		100
Cleveland	Case School of Applied Science	4/21/38	2	158
San Francisco	University of California, University of Santa Clara, Stanford University	4/22/38	3	118
Totals—17 Sections, 35 Branches			65	1,807

were held as follows: North Eastern District meeting, Buffalo, N. Y., May 5–7, one session, eight papers; Pacific Coast convention, Spokane, Washington, August 31–September 3, two sessions, 11 papers; Middle Eastern District meeting, Akron, Ohio, October 13–15, one session, six papers.

The students also continued their participation in joint meetings with Sections, student conventions, etc. Comprehensive information on many phases of Branch activities appears in tables III to VII, inclusive.

The committee on safety, with the endorsement of the chairman of the committee on student Branches, suggested that each Branch have during the year "a paper dealing with some phase of the problem of the prevention of accidents or remedial measures after electrical shock." Such papers were presented at meetings of at least 24 Branches.

Of the 1,474 Enrolled Students whose terms expired on April 30, 1937, 703, or about 48 per cent, applied for admission as Associates. The corresponding figures last year were 1,253; 674; and about 54 per cent. The percentages for the preceding few years were about 50 per cent.

Shasta Dam New Construction Project

On June 1, 1937, bids were opened for Shasta Dam on the upper Sacramento River in California. With a concrete volume of 5,400,000 cubic yards and a height of 560 feet, the dam will exceed the 3,250,000-cubic-yard Boulder Dam and the 550-foot Grand Coulee Dam. Shasta Dam will be 14 miles north of Redding and five miles below the mouth of the Pit River. It is the key unit in the Central Valley irrigation and flood-control project of the United States Bureau of Reclamation, and will store water that will be used to replenish groundwater in the San Joaquin Valley and to check salt-water incursion from San Francisco Bay into the delta region of the San Joaquin and Sacramento Rivers.

A powerhouse at the dam will have initially four 70,000-kw 13,800-volt generators each connected to a 100,000-horsepower turbine operated under heads from 242 to 479 feet. The ultimate capacity is planned to be 350,000 kw. A transmission line will extend 200 miles south to the delta region.

It is estimated that a construction period of five years will be required.

Franklin Institute Dedicates Memorial; Presents Medals

In a three-day program at Philadelphia, Pa., May 19–21, 1937, of The Franklin Institute, formally dedicated "In Honor of Benjamin Franklin," a heroic white-marble statue of Franklin by James Earle Fraser was unveiled. The various medals awarded annually by the institute were presented to the 1938 recipients as one part of the program which included addresses by prominent speakers, conferring of honorary degrees by the University of Pennsylvania, a parade, and special museum exhibits.

William Frederick Durand, professor emeritus of mechanical engineering, Stanford University, and Charles A. Kraus, professor of chemistry and director of research in chemistry, Brown University, each received the Franklin Medal, highest award of The Franklin Institute, which is given annually "to those workers in physical science or technology, without regard to country, whose efforts have done most to advance a knowledge of physical science or its applications." Nine other medals also were presented to ten individuals (one post-humously) and two companies.

Among those delivering lectures on applied science was W. R. Whitney (A'01) vice-president in charge of research, General Electric Company, Schenectady, N. Y., who spoke on "It's Called Electricity." Herbert Hoover (HM'29) was the speaker at a banquet held on the final day of the program.

1938 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1939, may be submitted by any member in accordance with Section 1 of Article VI of the by-laws of the Lamme Medal committee, as quoted in the following:

The committee shall cause to be published in one or more issues of ELECTRICAL ENGINEERING, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specified specific information should be given regarding his individual contributions. Names of endorsers should be given as specified above.

The Lamme Medal, founded as a result of a bequest of the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company (deceased July 8, 1924), provides for the annual award by the Institute of a gold medal —together with bronze replica thereof— to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery"; and for the award of two such medals in some years if the accumulation of funds warrants.

The tenth (1937) Lamme Medal has been awarded to Doctor R. E. Doherty (A'16, M'27), president, Carnegie Institute of Technology, Pittsburgh, Pa., "for his extension of the theory of alternating current machinery, his skill in introducing that theory into practice, and his encouragement of young men to aspire to excellence in this field." Presentation will be made during the AIEE summer convention at Washington, D. C., June 20–24, 1938. A biographical sketch of Doctor Doherty appeared in ELECTRICAL ENGINEERING for March 1938, page 141.

Membership—

Mr. Institute Member:

Do the men working for you or associated with you know that you belong to the Institute? Have you ever invited one of them to attend a Section meeting as your guest? Your associate would appreciate such an invitation and he might ask you some questions about the Institute and how to join it. If he does, don't worry about the details but introduce him to a member of the membership committee and then bring another guest to the next meeting.

The membership committee and the Institute will thank you if you find it possible to follow this suggestion.

Fred B. Doolittle

Vice-Chairman, District No. 8,
National Membership Committee

A membership proposal form appears on page 16 of the advertising section of this issue

"Research Day" in New England

A region-wide co-operative effort to stimulate greater use of research by New England industry for the continuous development of new products was made on May 20, 1937, when the New England Council, in co-operation with the Engineering Societies of New England, Inc., and eight New England colleges staged the first annual New England Research Day with meetings at Durham, N. H., Augusta, Me., Boston and Worcester, Mass., Providence R. I., and Hartford, Conn.

The all-day programs included visits to leading plant and institutional laboratories, luncheon and dinner meetings, and exhibits of new products developed by New England manufacturers through the use of research. Among speakers at the various meetings were K. T. Compton (F'31) and Vannevar Bush (A'15, F'24) of Massachusetts Institute of Technology. F. W. Bliss (A'30) president of the Engineering Societies of New England, Inc., in a joint statement with R. W. Sulloway, said, in part, "Research creates industry and develops new possibilities of employment. It widens the horizon of the manufacturer, discovers new and better production methods and equipment, makes possible the development of new products and the further development of old products, and brings prices and goods within the reach of more and more consumers . . . all of our industrialists, large and small, should realize the vital necessity of employing research methods."

Co-operating colleges were the University of Maine, University of New Hampshire, Massachusetts Institute of Technology, Harvard School of Engineering, Worcester Polytechnic Institute, Brown University, Connecticut State College, and Yale University.

Future Meetings of Other Societies

American Association for the Advancement of Science. Summer meeting, June 27–July 2, Ottawa, Can.

American Physical Society. 221st meeting, June 22–24, San Diego, Calif.

222d meeting, June 24–25, Toronto, Can.

American Society for Testing Materials. Annual meeting, June 27–July 1, Atlantic City, N. J.

American Society of Civil Engineers. Annual convention, July 20–22, Salt Lake City, Utah.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 20–22, Hot Springs, Va.

American Society of Mechanical Engineers. Semiannual meeting, June 20–24, St. Louis, Mo.

American Society of Refrigerating Engineers. Spring meeting, June 20–24, State College, Pa.

Canadian Electrical Association. Annual convention, June 22–24, Seigniory Club, Province of Quebec, Can.

Illuminating Engineering Society. Annual convention, August 29–September 1, Minneapolis, Minn.

Institute of Radio Engineers. Annual convention, June 16–18, New York, N. Y.

International Conference of Naval Architects and Marine Engineers. June 16–18, London, England.

International Engineering Congress. June 21–24, Glasgow, Scotland.

National Electrical Contractors Association. September 12–15, Detroit, Mich.

Society for the Promotion of Engineering Education. Annual meeting, June 27–30, College Station, Texas.

Society of Chemical Industry. Annual meeting, June 20–22, Ottawa, Can.

New Facilities for Scientific Activities

Office and laboratory space together with services and facilities as desired have been offered by Electrical Testing Laboratories, Inc., New York, N. Y., through a rental plan for any scientific, technical, trade, or institutional activity. The laboratories recently have acquired a larger building, adjacent to the quarters they have occupied since 1904, and space beyond their requirements is available for rental.

The facilities offered to tenants include a storeroom, comprehensive equipment of instruments, machine and carpenter shops, and photographic, photostatic, stenographic, mimeographing, accounting, and telephone and telephone-message services. Part or all of these may be had to meet the individual needs of tenants.

Steam Generating Stations. Recently published by *Science et Industrie*, Paris, France, a book entitled "L'Évolution Des Grandes Centrales Thermiques" outlines in some detail the evolution of large steam generating stations throughout the world. The book, which is in French, is divided into three parts: part I, which emphasizes principally French engineering practice, contains 11 papers on the design and operation of steam central stations, together with abstracts of five foreign papers; part II contains descriptions of large French central stations; and part III describes new equipment for central stations. Copies of the book may be obtained at a cost of 45 francs (in France 40 francs) from *Science et Industrie*, 29, Rue De Berri, Paris (8e) France.

ASHVE Announces Air-Conditioning Study

The 1938 program of research announced by the American Society of Heating and Ventilating Engineers lays renewed emphasis on the need for more highly organized and co-ordinated studies of the physiological aspects of air conditioning. W. L. Fleisher, chairman of the society's committee on research has outlined a long-range study designed to widen the industry's existing knowledge of problems vital to the progress of air conditioning. More than 50 scientists, physicians, surgeons, public health authorities, and engineers, will co-operate in the study.

One of the important phases of the research program will be a more extensive study of sensations of comfort experienced under varying artificial conditions of the atmosphere, especially in summer, and a comprehensive investigation of methods for cleaning the air of minute impurities by mechanical and electrical means. Possibilities in new methods of radiant heating in their effect on comfort also will be studied. The work will be carried out through several committees.

New Antenna for WGY

A new 625-foot radiator for WGY, radio-broadcasting station of the General Electric Company at Schenectady, N. Y., recently was placed in service with expectations of increased range. The trenches of the grounding system, which contains 14 miles of wire, may be seen in the view reproduced here. The tower, nine feet square, is guyed by eight lines broken by insulators into segments; its weight rests on a base insulator which was tested in the Bureau of Standards to withstand 2,000,000 pounds, or four times the normal load.

Baekeland to Receive Medal. Announcement has been made that Doctor Leo H. Baekeland, inventor of Bakelite, has been elected to receive the Messel Medal for 1938. This medal is awarded by the Society of Chemical Industry every two years for outstanding achievement in science. It was founded in 1922 in honor of Rudolph Messel, benefactor, one of the original members, and twice president of the Society of

Chemical Industry. The medal will be presented to Doctor Baekeland at the annual meeting of the society in Ottawa, Canada, on June 20, 1938.

American Engineering Council

AEC Holds First Forum in Philadelphia

Carrying out one of the first steps in its new program of activities (as reported in ELECTRICAL ENGINEERING for May, pages 228–9) American Engineering Council held the first of its projected series of forums at the Engineers' Club of Philadelphia, Pa., May 13, 1938, devoted to the subject "Employment and the Engineer's Relation to It." The program was arranged in two sessions, one following a general luncheon gathering, and the other following dinner in the evening. The 125 engineers and others who were present for the afternoon session engaged so actively in discussion that the meeting finally had to be declared adjourned to enable the club staff to make ready for dinner. The complete program was as follows:

AFTERNOON SESSION

Chairman—William L. Batt, president, SKF Industries, Philadelphia; member, AEC executive committee.

1:00 Luncheon.

1:30 Greetings from Engineers of Philadelphia, C. E. Bonine (A'03) president, Engineers' Club of Philadelphia.

1:45 Plan and Purpose of Forums of American Engineering Council, F. A. Allner (A'12, M'14) vice-president, Pennsylvania Water and Power Company, Baltimore, Md.; chairman, AEC public affairs committee.

2:00 Labor Policy and Prospects for Employment, Leo Wolman, economist, National Bureau of Economic Research, professor of economics, Columbia University, New York, N. Y.

3:45 The Contributions of Technology to Employment, L. J. Fletcher, assistant general sales manager, Caterpillar Tractor Company, Peoria, Ill.; member, AEC executive committee.

Discussion.

EVENING SESSION

Chairman—William McClellan (A'04, F'12) president, Potomac Electric Power Company; president AEC.

6:30 Dinner.

7:30 Technology and Competition, Stephen DuBrul, economist, General Motors Corporation, Detroit, Mich.

8:15 Relation of Technology to Finance, W. J. Kelly, president, Machinery and Allied Products Institute, and president, Arthur J. O'Leary and Sons, Chicago, Ill.

9:00 Summary of Conference.

Adjournment.

Objective of the AEC forums, as described by Mr. Allner, is to provide opportunities for the discussion with recognized authorities of various problems of public importance in which engineers should have a part.

Further details of the Philadelphia forum may be covered in later issues of ELECTRICAL ENGINEERING.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Wave Shape of Magnetizing Currents

To the Editor:

It has been known for a long time that the nonlinear relation between the flux and the magnetizing current in an iron-core transformer or choke coil results in the formation of harmonics in the magnetizing current. The magnitude of these harmonics can be obtained approximately by means of graphical methods. The following mathematical solution is, I believe, new.

Take the B-H curve for the iron and using the part of it between $B = 0$ and $B = B_M$—the latter point being flux density corresponding to E_{max} of the impressed electromotive force and express the relation in the form

$$H = K(B + aB^n + bB^{n_1} +) \qquad (1)$$

Then if the impressed electromotive force is sinusoidal, $B = K_1 \sin x$ and

$$I = K_2 H = KK_2 \left[K_1 \sin x + a(K_1 \sin x)^n + b(K_1 \sin x)^{n_1} + \ldots\right] \qquad (2)$$

In general two terms of equation 2 will be sufficient to provide a formula which fits the B-H curve fairly closely. $(\sin x)^n$ may be expanded in terms of odd harmonics as follows:

$$(\sin x)^n = \frac{\left[\sin x - \frac{n-1}{n+3}\sin 3x\right]}{D} + \frac{\left[\frac{(n-1)(n-3)}{(n-3)(n+5)}\sin 5x\right]}{D}$$

where $D =$

$$1 + \frac{n-1}{n+3} + \frac{(n-1)(n-3)}{(n+3)(n+5)} + \ldots$$

As this series converges rather slowly it may be more convenient to use the following summation of the series:

$$D = 2^n\left[\Gamma\left(\frac{n}{2} + \frac{3}{2}\right)\right]^2\left[(n+2)\right]^{-1}$$

This may be readily evaluated by reference to a table of gamma functions.

A rigorous proof of these formulas is too lengthy to be given here, but it may be mentioned that they are valid for all positive values of n.

Very truly yours,

JOHN L. CLARKE (A'17, M'30)

(Transmission Engineer, The Bell Telephone Company of Canada, Montreal, Que.)

Magnetic Force of a Solenoid

To the Editor:

The method generally employed for determining the axial and radial components of the magnetic force of a one-layer cylindrical solenoid makes use of the vector potential. While no inherent difficulties are connected with this, the calculations nevertheless are lengthy. The method here described is simpler, as it presupposes only Ampere's law. It is known that this law, which is usually given in the form

$$dH = \frac{ids\sin\psi}{r^2}$$

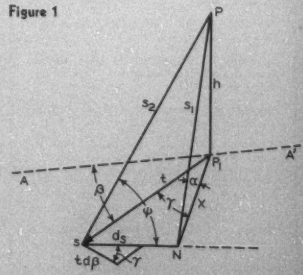
where i is the current, ds an element of the circuit, r the distance of the point for which dH is to be calculated from the element ds, and ψ the angle formed by ds and r. For a plane curve and for all points P in its plane this equation can be written

$$dH = \frac{id\beta}{r}$$

where β is the angle formed by r with a fixed straight through any point P. The question arises whether a similar transformation is also possible for points not in the plane of the curve. In figure 1 let h be the distance of point P from the plane of the curve of which ds is an element. Through the foot point P_1 of h the straight line AA' is drawn and the angle β is formed by the radius vector t and AA'. If s_2 is the distance from ds at point S to P then

$$dH = \frac{ids\sin\psi}{S_2^2} \qquad (1)$$

Figure 1



where ψ is the angle formed by ds and s_2. This magnetic force is perpendicular to the plane formed by ds and S_2 and its axial component will be parallel to h. If we draw a perpendicular X from P_1 to the extension of ds and join its foot point N with P we obtain two rectangular triangles P_1NP and PNS. In these triangles

$$\frac{PN}{PS} = \frac{S_1}{S_2} = \sin\psi$$

and

$$\frac{P_1N}{PN} = \frac{X}{S_1} = \cos\alpha$$

In figure 2 these two triangles have each been rotated by 90 degrees in opposite directions through space around x and t as axis, respectively, and they both are now in the plane of the curve. The axial component dH_a is $dH\cos\alpha$, for dH is perpendicular to the plane of the triangle PSN and therefore also perpendicular to s_1. Furthermore

$$ds = \frac{l\,d\beta}{\cos\gamma} \text{ and } x = t\cos\gamma$$

Inserting all these values in equation 1 we obtain

$$dH_a = \frac{ids\sin\psi\cos\alpha}{S_1^2} = \frac{it^3d\beta}{s_2^3} = \frac{it^3d\beta}{\sqrt{t^2+h^2}^3}$$

$$H_a = i\int_{\beta=0}^{2\pi}\frac{t^3d\beta}{\sqrt{t^2+h^2}^3}$$

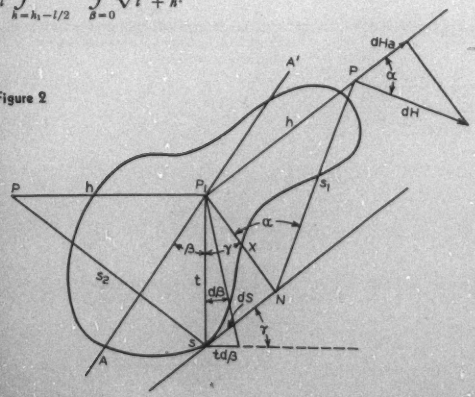
To calculate the axial component of the magnetic force of a cylindrical solenoid of any cross section with n turns, length l and with current I for any point P (figure 3) with a distance h_1 counted from the center plane of the solenoid we need only form the double integral

$$\frac{In}{l}\int_{h=h_1-l/2}^{h_1+l/2}dh\int_{\beta=0}^{2\pi}\frac{t^3d\beta}{\sqrt{t^2+h^2}^3} = H_{sa}$$

writing this

$$\frac{In}{l}\int_{h=h_1-l/2}^{h_1+l/2}\int_{\beta=0}^{2\pi}\frac{t^3d\beta dh}{\sqrt{t+h^2}^3}$$

Figure 2



and performing the integration in regard to h, we obtain

$$\frac{In}{l}\int_{\beta=0}^{2\pi}d\beta\frac{h}{\sqrt{t^2+h^2}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

$$H_{sa} = \frac{In}{l}\int_{\beta=0}^{2\pi}d\beta\left[\frac{h_1+\frac{l}{2}}{\sqrt{t^2+\left(h_1+\frac{l}{2}\right)^2}} - \frac{h_1-\frac{l}{2}}{\sqrt{t^2+\left(h_1-\frac{l}{2}\right)^2}}\right]$$

If the cross section is a circle of radius R, then for the axis of the cylinder or solenoid

$$H_{sa} = \frac{2\pi In}{l}\left[\frac{h_1+\frac{l}{2}}{\sqrt{R^2+\left(h_1+\frac{l}{2}\right)^2}} - \frac{h_1-\frac{l}{2}}{\sqrt{R^2+\left(h_1-\frac{l}{2}\right)^2}}\right]$$

Figure 3

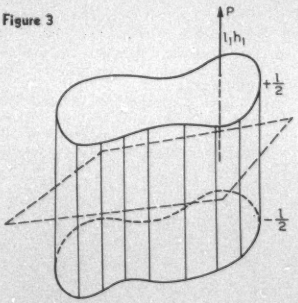
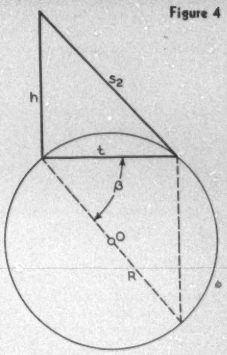


Figure 4



the well-known formula. If the point h_1 is situated in a perpendicular to the plane of the circles and passing through a point on its circumference then

$$H_{sa} = \frac{In}{l}\int_{\beta=0}^{2\pi}d\beta\frac{h}{\sqrt{(2R)^2\cos^2\beta+h^2}}\Bigg|_{h-l/2}^{h_1+l/2}$$

with regard to figure 4 we can write this, applying at the same time some transformations,

$$H_{sa} = \frac{2In}{l}\int_{\beta=0}^{\pi/2}\frac{h}{\sqrt{4R^2+h^2}}\times \frac{d\beta}{\sqrt{1-\frac{h^2}{4R^2+h^2}\sin^2\beta}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

For the center plane $h_1 = 0$ and

$$H_{sa} = \frac{2In}{\sqrt{4R^2+\left(\frac{l}{2}\right)^2}}\times \int_{\beta=0}^{\pi/2}\frac{d\beta}{\sqrt{1-\frac{4R^2\sin^2\beta}{4R^2+\left(\frac{l}{2}\right)^2}}}$$

But

$$\int_{\beta=0}^{\pi/2}\frac{d\beta}{\sqrt{1-\frac{4R^2\sin^2\beta}{4R^2+\left(\frac{l}{2}\right)^2}}}$$

is an elliptical integral which if R is assumed as $l/10 = 0.1l$, may be taken as $\pi/2$ and we therefore get

$$H_{sa} = \frac{In}{l}\frac{\pi}{\sqrt{0.04+0.25}}$$

while the axial component for the center is given by

$$\frac{2\pi In}{l\sqrt{0.01+0.25}}$$

which is about twice the value of that at the circumference.

To determine the axial magnetic force

for a solenoid with circular cross section for any point P we proceed in the following manner: In the integrals

$$\int_{\beta=0}^{2\pi} \frac{d\beta\left(h_1+\frac{l}{2}\right)}{\sqrt{t^2+\left(h_1+\frac{l}{2}\right)^2}}$$

and

$$\int_{\beta=0}^{2\pi} \frac{d\beta\left(h_1-\frac{l}{2}\right)}{\sqrt{t^2+\left(h_1-\frac{l}{2}\right)^2}}$$

in which $h_1 + l/2$ and $h_1 - l/2$ (figure 5) are perpendicular to t in space, therefore the factors multiplying $d\beta$ are sines of angles in rectangular triangles. Turning the triangle P_1PS with P_1S as axis by 90 degrees it then falls in the plane of the circle with radius R and O as center. As $h_1 + l/2$ and $h_1 - l/2$ are perpendicular to t their end points will describe circles with P' as center and with $h_1 + l/2$ and $h_1 - l/2$ as radii, respectively, when the extremity of t describes the circle with O as center.

From figure 5 it is readily seen that

$$\frac{h_1+\frac{l}{2}}{s_2'} = \frac{VW}{2R} \text{ and } \frac{h_1-\frac{l}{2}}{s_2''} = \frac{UW}{2R}$$

The lines $VW = z_1$ and $UW = z_2$ are obtained by joining the points of intersection of the lines s_2' and s_2'' and t with the circle of radius R. We therefore can write

$$\int_{\beta=0}^{2\pi} \frac{d\beta\left(h_1 \pm \frac{l}{2}\right)}{\sqrt{h_2+\left(h_1 \pm \frac{l}{2}\right)^2}} = \int_{\beta=0}^{2\pi} \frac{z_1 d}{2R}\beta - \int_{\beta=0}^{2\pi} \frac{z_2 d}{2R}\beta$$

If we then plot the various values $\sqrt{z_1}$ and $\sqrt{z_2}$ on lines forming the respective angles β with OP_1 we obtain closed curves the areas of which expressed in polar co-ordinates will be porportional to the integrals

$$\int_{\beta=0}^{2\pi} \frac{d\beta\left(h_1 \pm \frac{l}{2}\right)}{\sqrt{t^2+\left(h_1 \pm \frac{l}{2}\right)^2}}$$

as the area is given by

$$\int_{\beta=0}^{\beta_1} \frac{\sqrt{z^2}d\beta}{2} = \frac{1}{2}\int_{\beta=0}^{\beta_1} zd\beta$$

To determine the factor of porportionality we proceed as follows: Let us assume that we have obtained the value of the area by aid of a planimeter with a constant c; that is, a reading b of the planimeter is equal to bc square centimeters. Therefore if

$$\int_{\beta=0}^{\beta_1} \sqrt{z^2}d\beta = bc \text{ square centimeters}$$

then

$$\int_{\beta=0}^{\beta_1} zd\beta = 2bc$$

and bc/R is the value of the integral and finally

$$H_{sa} = \frac{In}{l}\frac{bc}{R} \times$$

If the point P_1 is situated within the circle then the curve the area of which represents

$$\int_{\beta=0}^{2\pi} \sqrt{z^2}d\beta$$

surrounds this point, if P_1 is to the outside of the circle then these curves will be at one side of this point.

As I have pointed out the formula for H_{sa} holds good for a cylindrical solenoid of any cross section and we may easily apply it for figuring H_{sa} along the axis of a rectangular solenoid. If $2R$ be the length of the sides of the square then as shown in figure 6, $t = R/\cos\beta$ and

$$H_{sa} = \frac{8In}{l}\int_{\beta=0}^{\pi/4} \frac{hd\beta}{\sqrt{\left(\frac{R}{\cos\beta}\right)^2+h^2}}\Bigg|_{h-l/2}^{h+l/2}$$

$$H_{sa} = \frac{8In}{l} \times \int_{\beta=0}^{\pi/4} \frac{\left(h_1 \pm \frac{l}{2}\right)\cos\beta d\beta}{\sqrt{R^2+\left(h_1 \pm \frac{l}{2}\right)^2-\left(h_1 \pm \frac{l}{2}\right)^2\sin^2\beta}}$$

and finally

$$H_{sa} = \frac{8In}{l}\left[\sin^{-1}\frac{1}{\sqrt{2}}\frac{h_1+\frac{l}{2}}{\sqrt{R^2+\left(h_1+\frac{l}{2}\right)^2}} - \sin^{-1}\frac{1}{\sqrt{2}}\frac{h_1-\frac{l}{2}}{\sqrt{R^2+\left(h_1-\frac{l}{2}\right)^2}}\right]$$

The similarity of this expression with that of a solenoid with circular cross section is evident, a result which one would expect. For small values of the arc this may be written

$$H_{sa} = \frac{8In}{\sqrt{2}l}\left[\frac{h_1+\frac{l}{2}}{\sqrt{R^2+\left(h_1+\frac{l}{2}\right)^2}} - \frac{h_1-\frac{l}{2}}{\sqrt{R^2+\left(h_1-\frac{l}{2}\right)^2}}\right]$$

It is not possible to develop a graphical method for the determination of the radial component of a solenoid with circular cross section with β as independent variable. But by introducing polar co-ordinates with the center of the circle as origin and with the angle ϕ at the center as independent variable we obtain an expression which readily can be integrated and permits also of a graphical solution. Starting again from equation 1 we obtain

$$dH_r = \frac{inRd\phi \sin\psi \sin\alpha}{S_2^2}$$

where (figure 1)

$$\sin\psi = \frac{S_1}{S_2}$$

$$\sin\alpha = \frac{h}{s_1}$$

and (figure 7)

$$S_2 = \sqrt{R^2+\rho^2-2\rho R\cos\phi+h^2}$$

therefore

$$dH_r = \frac{inRd\psi}{\sqrt{R^2+\phi^2-2\phi R\cos\psi+h^2}}$$

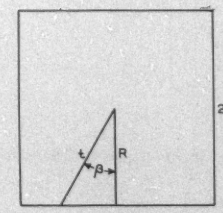


Figure 6

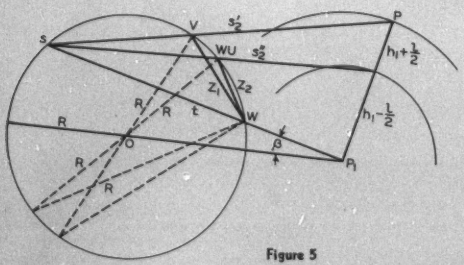


Figure 5

While all differentials dH_{sa} of H_{sa} fall in the same direction, namely that of h, this is no longer true of the differentials dH_r, each of which falls in the direction of the respective radius R belonging to the element $Rd\psi$. But by inspection of figure 7 it is evident that dH_r may be decomposed into one component falling in the direction of ρ the line joining the foot point P_1 of h with O and into another perpendicular thereto. For reasons of symmetry these latter cancel out while the former being $dH_r \cos\phi$ add up to form a resultant in the direction OP_1 and we so obtain for the radial component of the solenoid

$$dH_r = \frac{In}{l}\int_{h=h_1-l/2}^{h_1+l/2} dh \times \int_{\phi=0}^{2\pi} \frac{d\phi R h \cos\phi}{\sqrt{R^2+\rho^2+h^2-2\rho R\cos\phi}^3}$$

The first integration gives

$$-\frac{In}{l} \times \int_{\phi=0}^{2\pi} \frac{R\cos\phi d\phi}{\sqrt{R^2+\rho^2+h^2-2\rho R\cos\phi}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

For reasons of symmetry this may be written

$$-\frac{2In}{l} \times \int_{\phi=0}^{\pi} \frac{R\cos\phi d\phi}{\sqrt{R^2+\rho^2+h^2-2\rho R\cos\phi}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

By making the following substitutions

$$\phi = (\pi - 2X)$$

$$d\phi = -2dX$$

$$\cos\phi = -\cos 2X$$

and

$$\cos 2X = 1 - 2\sin^2\frac{X}{2}$$

the integral is transformed to

$$-\frac{4InR}{l}\int_{X=\pi/2}^{0} \frac{(1-2\sin^2 X)dX}{\sqrt{(R+\rho)^2+h^2}\sqrt{1-k^2\sin^2 X}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

where

$$k^2 = \frac{4R\rho}{(R+\rho)^2+h^2}$$

Bearing in mind that

$$\int_{X=\pi/2}^{0} \frac{dX}{\sqrt{1-k^2\sin^2 X}} = -K$$

or the elliptical integral of first order and

$$\int_{X=\pi/2}^{0} \frac{dX}{\sqrt{1-k^2\sin^2 X}}dX = -E$$

or the elliptical of second order (see appendix) and by reversing the order of substitution the final result is

$$H_r = \frac{2In}{l}\sqrt{\frac{R}{\rho}}\left\{\frac{2}{k}(K-E_1)-kK\right\}\Bigg|_{h_1+l/2}^{h_1-l/2}$$

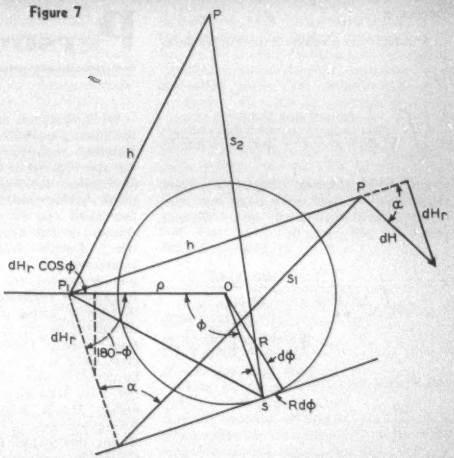
For the center plane of the solenoid h_1 is zero and therefore H_r is zero irrespective of ρ as the value of the expression in brackets for the upper and lower limit is numerically equal but with reversed sign. This signifies that the center plane is an equipotential surface and the lines of magnetic force are perpendicular to this plane. It is also easily seen that the end planes are no equipotential surfaces, while for the axis of the solenoid no radial component exists.

For the graphical solution we again start from the integral expression

$$H_r = -\frac{2In}{l} \times \int_{\phi=0}^{\pi} \frac{R\cos\phi\, d\phi}{\sqrt{R^2+\rho^2+h^2-2\rho R\cos\phi}}\Bigg|_{h_1-l/2}^{h_1+l/2}$$

By referring to figure 8 we see that

Figure 7



$$\sqrt{R^2+\rho^2+h^2-2\rho R\cos\phi}\Big|_{h_1-l/2}^{h_1+l/2}$$

is represented by the line $SP \equiv S_2$ in the rectangular triangle P_1SP. Constructing a second rectangular triangle having S_2 as hypotenuse and $R\cos\phi$ as second side forming with S_2 angle X_1 we then prolong $R\cos\phi$ until it intersects at U with the circle of radius R and O as center. Drawing a diameter $2R$ from the second point of intersection V of S_2 with the circle, then the rectangular triangle VWU will be similar to triangle PQS and therefore

$$\frac{R\cos\phi}{\sqrt{R^2+\rho^2+\left(h_1+\frac{l}{2}\right)^2-2\rho R\cos\phi}} = \frac{VU}{VW} \equiv \frac{X_1}{2R}$$

In like manner for the distance $h_1-l/2X_2$ is obtained.

If we plot $\sqrt{X_1}$ and $-\sqrt{X_2}$ as radius vector under the respective angle ϕ from O as center, then again the area of the so formed curve will be proportional to the radial component of the magnetic force, and by multiplying with the same constants as above, namely

$\frac{In}{l}\frac{bc}{R}$ (b planimeter reading, c constant of planimeter) we finally get H_r.

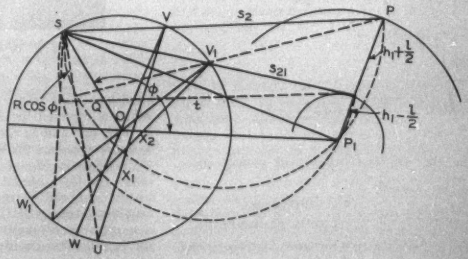


Figure 8

APPENDIX

Although the transformations of the integral

$$S = -\int_{X=\pi/2}^{0} \frac{(1 - 2\sin^2 X)dX}{\sqrt{R^2 + \rho^2 + h^2 + 2\rho R(1 - 2\sin^2 X)}}$$

to obtain the elliptical integrals are quite elementary we shall carry them out here in more detail than in the text. We will write

$$S = -\int_{X=\pi/2}^{0} \frac{(1 - 2\sin^2 X)\,dX}{\sqrt{(R+\rho)^2 + h^2} \times \sqrt{1 - \frac{4R\rho \sin^2 X}{(R+\rho)^2 + h^2}}}$$

and writing for

$$\frac{4R}{(R+\rho)^2 + h^2} = k^2$$

the expression

$$S = -\frac{1}{\sqrt{(R+\rho)^2 + h^2}} \times \left\{ \int_{X=\pi/2}^{0} \frac{dX}{\sqrt{1 - k^2 \sin^2 X}} - \int_{X=\pi/2}^{0} \frac{2}{k^2} \frac{k^2 \sin^2 X\, dx}{\sqrt{1 - k^2 \sin^2 X}} \right\}$$

$$\int_{X=\pi/2}^{0} \frac{dX}{\sqrt{1 - k^2 \sin^2 X}} = -K$$

or the elliptical integral of the first order with reversed sign

$$\int_{X=\pi/2}^{0} \frac{2}{k^2} \frac{k^2 \sin^2 X dX}{\sqrt{1 - k^2 \sin^2 X}} =$$

$$\int_{X=\pi/2}^{0} \frac{2}{k^2} \frac{[1 + k^2 \sin^2 X - 1]dx}{\sqrt{1 - k^2 \sin^2 X}} = M$$

$$-M = -\int_{X=\pi/2}^{0} \frac{2}{k^2} \sqrt{1 - k^2 \sin^2 X} dX + \int_{X=\pi/2}^{0} \frac{2}{k^2} \frac{dX}{\sqrt{1 - k^2 \sin^2 X}}$$

and

$$\int_{X=\pi/2}^{0} \sqrt{1 - k^2 \sin^2 X} dX = -E$$

or the elliptical integral of second order with reversed sign.

Very truly yours,

LIONEL FLEISCHMANN

(Aloey Ferguson Company, Cincinnati, Ohio)

Personal Items

W. R. WHITNEY (A'01) recently received the Marcellus Hartley Gold Medal of the National Academy of Sciences "to mark the appreciation of the National Academy of Sciences for eminent services to the public, performed without a view to monetary gains and by methods which in the opinion of the Academy are truly scientific." Doctor Whitney was born at Jamestown, N. Y., August 22, 1868. He was graduated from the Massachusetts Institute of Technology with the degree of bachelor of science in 1890, and in 1896 received the degree of doctor of philosophy from Leipzig University. Honorary degrees since have been conferred upon him by several universities. Since his graduation from Massachusetts Institute of Technology, Doctor Whitney has held the following positions at that institution: assistant instructor in general chemistry (1890–92), sanitary chemistry (1896–98), instructor in theoretical chemistry and proximate analysis (1898–1901), assistant professor of theoretical chemistry (1901–04), nonresident associate professor of theoretical chemistry (1904–08), and nonresident professor of chemical research since 1908. In 1900 when the research laboratories of the General Electric Company were established at Schenectady, N. Y., Doctor Whitney was appointed director of research. In 1928 he became vice-president of the company and director of research. In 1932 he retired from active service and was made vice-president in general charge of research, which position he has since held. Although Doctor Whitney's greatest personal activity has been in the field of chemistry, he has directed many researches that have made outstanding contributions to the electrical industry. He has contributed generously to technical literature, having

W. R. WHITNEY

published more than 80 papers. Doctor Whitney received the AIEE Edison Medal in 1934, and among the many other honors he has received are the Willard Gibbs Medal, 1916; Chandler Medal, 1920; Perkin Medal, 1921; the Gold Medal of the National Institute of Social Sciences, 1928; and the Franklin Medal, 1931. Doctor Whitney is a member of many technical societies and is a member for life of the Institute.

E. F. PEARSON (A'20, F'37) has relinquished his duties as chief engineer of the Northwestern Electric Company, Portland, Ore., to become assistant to the president of the Pacific Power and Light Company, Portland. In his new position his services will be available in an advisory capacity to the Northwestern Electric Company. Mr. Pearson was born October 26, 1890, at Virginia City, Nev., and was graduated from the University of Nevada in 1912 with the degrees of bachelor of science and electrical engineer. He joined

E. F. PEARSON

the Northwestern Electric Company immediately following his graduation, and has served that company continuously, except for a brief service in the United States Army during the World War. He became chief engineer in 1935. Mr. Pearson was chairman of the AIEE Portland Section during 1923–24, and during the same year he was a member of the national membership committee. At present he is a member of the committee on power generation, and is general chairman of the 1938 Pacific Coast convention.

J. P. JACKSON (A'92, F'12) for many years in charge of personnel for the Consolidated Edison Company of New York, Inc., New York, N. Y., and the United Electric Light and Power Companies, recently retired from active service. Colonel Jackson was born September 27, 1868 in Philadelphia, Pa., and was graduated from Pennsylvania State College with the degrees of bachelor of science in mechanical engineering (1887) and mechanical engineer (1892). Later the University of Pittsburgh conferred upon him the degree of doctor of science. His first position in the electrical industry was as a wireman for the Philadelphia Electric Company in 1889. Later he was associated with the Sprague Electric Company as superintendent of street railway construction before entering the teaching profession as director of the mechanical department of Fisk University in 1890. In 1892 Colonel Jackson was appointed to the faculty of Pennsylvania State College, where he remained until

1913, first as professor of electrical engineering and later as dean of the college of engineering. During the World War he was commissioned as a colonel in the United States Corps of Engineers, and for distinguished service was decorated by the French and Italian governments; he received a citation from the United States government for meritorious service. He joined The New York Edison Company as assistant to the vice-president in 1924 and two years later was made also manager of the personnel bureau. He became head of the personnel department of the Consolidated Edison Company in 1937. Colonel Jackson is author or co-author of several technical books and papers. He served the Institute as a member of the committees on education, 1926–28; and safety, 1926–30 (chairman 1926–28) He has served as Institute representative on the Commission of Washington Awards, National Fire Protection Association, National Fire Waste Council, National Safety Council, and the advisory committee to the Museum of Science and Industry of New York (chairman 1926–37). He is a member for life of the Institute and a member of The American Society of Mechanical Engineers, Franklin Institute, Eta Kappa Nu, and other scientific and social organizations.

WILLIAM ARTHUR (A'12, M'17) has been appointed Philadelphia (Pa.) district office manager of the Allis-Chalmers Manufacturing Company. Mr. Arthur was born in England in 1880 and received his technical education at the Lancashire Railway Technical Institute and at Liverpool University. After serving an engineering apprenticeship at Horwich, England, he became assistant engineer in the electric traction divison of the Lancashire and Liverpool Railway, later being appointed assistant resident electrical engineer in charge of the Liverpool-Southport electrified systems. In 1907 he came to the United States and was employed in the electric railway department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Later Mr. Arthur became engaged in various manufacturing and consulting engineering activities before becoming affiliated with the American Brown-Boveri Electric Corporation in 1925. When that company's electrical interests were absorbed by the Allis-Chalmers Company in 1931, Mr. Arthur was retained as special representative for railway traction and mercury arc rectifiers, with offices at New York, N. Y. Mr. Arthur is a member of the American Transit Association.

G. A. ANDEREGG (A'04, M'30) has retired as cable development engineer of the Bell Telephone Laboratories, New York, N. Y. Mr. Anderegg was born at Ragersville, Ohio, March 30, 1873, and was graduated from Oberlin College with the degree of bachelor of science in 1899. He then attended Harvard University, where he received the degrees of bachelor of arts and master of arts in 1900 and 1902, respectively. Following his graduation in 1902 he joined the Western Electric Company at Chicago, Ill., and a year later was transferred to the development laboratory in New York. In 1904 he returned to Harvard University to fill a temporary appointment as instructor in electrical engineering. During the three following years he served as associate professor of electrical engineering at The Ohio State University, but returned to the engineering department of the Western Electric Company in New York in 1908. Since 1909 Mr. Anderegg has been engaged in the development and design of lead covered telephone cables, and since 1913 has been in charge of that work, first for the Western Electric Company, and later for the Bell Telephone Laboratories.

W. K. DUNLAP (A'89, F'12) has retired as acting vice-president of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Mr. Dunlap was born December 5, 1869 at Rochester, N. Y., and received his formal technical education at the University of Rochester. He began his industrial career with the Westinghouse Company as an apprentice engineer following his graduation in 1892. Two years later he was sent to Niagara Falls, N. Y. He remained there for six years as resident manager of operation, then went to Europe to observe electrical progress in Italy and Switzerland. Upon his return to the United States he became superintendent of construction for the Westinghouse Company. In 1904 Mr. Dunlap was promoted to the position of managing director of Westinghouse interests at the Louisiana Purchase Exposition at St. Louis, Mo. During the following year he became assistant to the vice-president and for several years directed service operations of the company. Mr. Dunlap is a member for life of the Institute.

R. A. MCCARTY (A'16, M'32) recently was transferred to South Philadelphia, Pa., as manager of the steam and stoker division of the Westinghouse Electric and Manufacturing Company. Formerly Mr. McCarty was manager of the small motor division of that company, with offices at Lima, Ohio. A native (1882) of Mooresburg, Tenn., he was graduated from the University of Tennessee in 1903, following which he entered the test course of the Westinghouse Company. He entered the power engineering division in 1906, and three years later was assigned to motor engineering. In 1910 he was made engineer in charge of insulation design and became section engineer a year later in the power engineering department. In 1928 Mr. McCarty was appointed division engineer, and two years later became manager of the power engineering department. He became manager of the generator division in 1935, and was transferred to Lima as manager of the small motor division in 1938.

W. L. CISLER (M'35) recently became assistant chief engineer, electric engineering department, Public Service Electric and Gas Company, Newark, N. J. Mr. Cisler was born October 8, 1897, at Marietta, Ohio, and was graduated from Cornell University with the degree of mechanical engineer in 1922. Immediately following his graduation he became associated with the Public Service Electric and Gas Company as a cadet engineer, and has been associated with that organization continuously. In 1926 he became assistant chief engineer at the Paterson (N. J.) generating station, in the following year he was made chief engineer at the Marion generating station, and in 1931 he was made planning and installation engineer in the Newark offices. Mr. Cisler became general superintendent of generation in 1935, and one year later was appointed assistant general manager.

C. E. STRYKER (A'21, F'35) has become a partner of the consulting-engineering firm of McKinsey, Wellington, and Company, Chicago, Ill. Mr. Stryker is a native (1897) of Chicago, and received the degrees of bachelor of science in electrical engineering (1917) and electrical engineer (1924) at the Armour Institute of Technology. For two years following his graduation he was employed as testing engineer for the Commonwealth Edison Company, Chicago. In 1920 Mr. Stryker became assistant professor of electrical engineering at Armour Institute of Technology, and at the same time served as electrical engineer for the Ozone Pure Airifier Company; later he served in the same capacity for the Underwriters Laboratories. In 1923 he became affiliated with the Fansteel Products Company, eventually becoming chief engineer and remaining with that company until 1936, when he resigned to join McKinsey, Wellington, and Company. He is a member of the Society of Automotive Engineers.

L. A. PIPES (A'37) has been appointed instructor in electrical engineering in the graduate school of engineering at Harvard University, Cambridge, Mass. A native (1910) of Mexico City, Mexico, Doctor Pipes was graduated from California Institute of Technology with the degree of bachelor of science in 1933. In the following year he enrolled as a graduate student at that institution, receiving at the same time an appointment as assistant in electrical engineering. At the end of that scholastic year he received his master of science degree, and in 1936 was granted the degree of doctor of philosophy. During 1936–37 Doctor Pipes was an instructor in electrical engineering at The Rice Institute, Houston, Texas, and in 1937–38 he was alumni research fellow at the University of Wisconsin, Madison. Doctor Pipes' new appointment becomes effective September 1, 1938.

A. V. KARPOV (M'22) recently resigned his position as designing engineer for the Aluminum Company of America, Pittsburgh, Pa., to devote his entire time to private practice as a consulting engineer, with offices in Pittsburgh. Mr. Karpov is a native (1886) of Kursk, Russia, and was graduated from the Darmstadt (Germany) Technical College and the Kharkov (Russia) Technical Institute. After serving as engineer in charge of several engineering projects

in Russia and Germany, he came to the United States in 1920 and secured employment as an engineer and designer for the Standard Arch Company, New York, N. Y. He has been associated with the Aluminum Company of America since 1928. In 1936 Mr. Karpov was awarded the Thomas Fitch Rowland prize of the American Society of Civil Engineers as co-author of a paper relating to bridge design.

H. F. Boe (M'30) has been made manager of the service department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Mr. Boe is a native (1884) of Mansfield, Ohio, and attended Carnegie Institute of Technology. He became affiliated with the Westinghouse Company in 1903 as a dynamo and motor tester, and continued at the East Pittsburgh works until 1915. For one year, during 1916–17 Mr. Boe was chief engineer and manager of the Vaile Kimes Company, Dayton, Ohio, following which he returned to the Westinghouse Company as a sales engineer in the Rochester, N. Y. offices. Since 1922 he has been successively manager of the Buffalo (N. Y.) sales office; eastern district sales manager, with headquarters in New York, N. Y.; and commercial manager.

H. A. McLaughlin (A'24, M'30) has been appointed test engineer in charge of the electric testing section of Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y. Mr. McLaughlin became associated with that company as relay engineer in 1929 and has been protection engineer for several years. He was graduated in electrical engineering from the Polytechnic Institute of Brooklyn in 1923, following which he was engaged in test work and the design and application of protective equipment for the Brooklyn Edison Company. He was associated briefly with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., before joining the Central Hudson Gas and Electric Corporation.

E. J. Watz (A'28, M'34) recently was appointed branch manager of the General Electric X-Ray Corporation, Minneapolis, Minn. Mr. Watz was born in 1901 at Stockholm, Sweden, and has been affiliated with the General Electric X-Ray Corporation continuously since 1922. In that year he became a service engineer in the New York, N. Y. offices of that company; in 1925 he was made manager of the New York service department; and for the last ten years he has been engaged in sales engineering work.

C. R. Beardsley (A'08, F'30) has been transferred to the Consolidated Edison Company of New York, Inc., New York, N. Y., as assistant manager of the contract control and inspection department. Mr. Beardsley formerly was general superintendent of distribution construction for the Brooklyn Edison Company, Inc., Brooklyn, N. Y. He is a director of the Institute.

N. C. Goin (M'24) has been made sales manager, gearing division, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. Mr. Goin has been associated with the Westinghouse Company continuously since 1917, except for a two-year period in the United States Army during the World War. Since 1921 he has been a sales engineer in the Pittsburgh offices.

Ernest Thompson (A'33) sales representative for the Electric Controller and Manufacturing Company has been transferred to the St. Louis (Mo.) offices of that company. Mr. Thompson has been associated with the Electric Controller and Manufacturing Company since 1929 and has been assigned to the Chicago offices since 1935.

V. A. Hanson (A'34) vice-president and chief engineer of the Power Transmission Council, has been transferred from Boston, Mass. to Detroit, Mich., where he will conduct a transmission survey of manufacturing plants allied or identified with the automotive industry. Mr. Hanson has been located at the Boston headquarters for the last two years.

R. N. Stoddard (M'34) has been transferred to the Westinghouse Electric and Manufacturing Company lamp division, Bloomfield, N. J. In his new position Mr. Stoddard will specialize in problems in electronics. Formerly he was employed in the East Pittsburgh, Pa. works of the Westinghouse Company.

W. H. Harries (A'36) recently was appointed junior electrical engineer for the National Advisory Committee for Aeronautics at Langley Field, Va. Formerly Mr. Harries was a levelman for the United States Bureau of Reclamation, Coulee Dam, Wash.

J. R. Maull (A'37) recently became a cadet engineer for the Public Service Electric and Gas Company, Newark, N. J. Mr. Maull has been an assistant in the department of electrical engineering of Massachusetts Institute of Technology, Cambridge.

H. A. Egeberg (A'28) has been appointed investigating electrical engineer to the State Electricity Commission, Brisbane, Queensland, Australia. Formerly Mr. Egeberg was assistant electrical engineer for the department of public works, Brisbane.

J. N. Keck (A'37) recently became a student engineer for the Illinois-Iowa Power Company, Champaign, Ill. Mr. Keck formerly was assistant to the chief of test department, Moloney Electric Company, St. Louis, Mo.

F. E. Bell (A'35) has assumed new duties at Guntersville Dam, Ala. Mr. Bell has been assistant construction engineer for the Tennessee Valley Authority at the Joe Wheeler Dam, Ala. He is vice-chairman of the AIEE Muscle Shoals Section.

W. E. Peterson (A'36) has been transferred to the Manistee, Mich., offices of the Consumers Power Company as power and lighting sales engineer. Until recently Mr. Peterson has been a draftsman in the Saginaw (Mich.) offices of that company.

W. F. Bergmann (A'36) has become assistant chief electrical designer for the engineering firm of Holway and Neuffer, Tulsa, Okla. Mr. Bergmann formerly was associated with the Public Utility Engineering and Service Corporation, Chicago, Ill.

Obituary

Malcolm Vau Watson (A'07, M'32) vice-president and general manager of the West Coast Power Company, California Public Service Company, and Western States Utilities Company, Portland, Ore., died April 25, 1938. Mr. Watson was born at Marquette, Kans., October 16, 1874. and was graduated from Kansas University in 1898 with the degree of bachelor of science in electrical engineering. After holding several preliminary positions he became chief electrician for the United States Reduction and Refining Company in 1902, remaining there until 1906, when he went to Zamora, Mexico, to become superintendent of hydroelectric stations for the Guanajuato Power Company. In the following year Mr. Watson was employed by the Colorado Power Company, Denver, as a designer of substations. In 1909 he became general manager of the Arizona Power Company, and six years later assumed the additional duties of chief engineer. Mr. Watson had been vice-president and general manager of the West Coast Power Company and its associated companies since 1927.

John William Freidenmann (M'30) district representative for the General Electric Company, Dubuque, Ia., died February 13, 1938. Mr. Friedenmann was born at Bennington, Vt., July 23, 1896, and attended Union College. In 1916 he was employed by the General Electric Company, Schenectady, N. Y., as a draftsman. In 1918 he became an engineer for the American Brake Shoe and Foundry Company, Erie, Pa., but remained there for only one year before joining the sales and advertising department of the Electric Service Supply Company. In 1923 he established his own electrical contracting and engineering business at Bennington, Vt., continuing in that business until 1928 when he became a regional merchandise specialist for the General Electric Company.

Anatoli Constantinovitch Seletzky (A'29, M'35) associate professor of electrical engineering, Case School of Applied Science, Cleveland, Ohio, died May 11, 1938 after a brief illness. Born May 29, 1905, at Volynia, Russia, Doctor Seletzky came to the United States and studied at The Johns Hopkins University, where he re-

ceived the degree of bachelor of science in electrical engineering in 1927. After serving briefly with the Brooklyn Edison Company and the Westinghouse Electric and Manufacturing Company, he returned to Johns Hopkins to study, and received the doctor of engineering degree there in 1930. In the same year he was appointed instructor in electrical engineering at Case School of Applied Science; in 1933 he was appointed assistant professor, and in 1937 was promoted to the rank of associate professor. Doctor Seletzky wrote many technical papers on electric circuit theory, power transmission lines, transformers, and amplifiers, and frequently was called as an expert consultant in patent litigations involving those subjects. He was a member of the current AIEE committee on instruments and measurements. In 1936 he received honorable mention in the selection of America's outstanding young electrical engineer by Eta Kappa Nu. He was a member of Tau Beta Pi and Sigma Xi.

MAYNARD DODD (M'24) assistant vice-president of the Commercial Cable Company, New York, N. Y., died April 10, 1938. Mr. Dodd was born April 1, 1869 at Glasgow, Scotland, and attended the West of Scotland Technical College. In 1886 he became an operator for the British Government Telegraphs, and remained with that service until 1889, when he resigned to join the Anglo-American Telegraph Company. Mr. Dodd became chief electrician of the Commercial Pacific Cable Company in 1905, with headquarters at Honolulu, T. H. In 1921 he was transferred to that company's head office at New York, N. Y., as an executive engineer, and one year later was appointed assistant vice-president of the Commercial Cable Company.

HENRY AUGUSTUS RATCLIFF (M'22) chief electrical engineer, London Power Company, Ltd., London, England died April 26, 1938. Mr. Ratcliff was born in 1877 at Nottingham, England, and received his technical education at the University College, Nottingham. In 1897 he became a member of the staff of the Manchester Corporation Electricity Department, where he held various positions, eventually becoming superintendent electrical engineer in 1921. Concurrently he served for many years as demonstrator and lecturer in the Manchester College of Technology. He became chief electrical engineer of the London Power Company in 1928.

HENRY WILLIAM CLOTHIER (M'17) director of A. Reyrolle and Company, Ltd., Hebburn-on-Tyne, England, died March 11, 1938. Mr. Clothier was born in London, England, April 3, 1872, and was educated at St. Mark's College Schools and the City and Guilds of London Institute. For ten years he was employed by S. Z. DeFerranti, Ltd., London, holding various positions including the managership of the switchgear department. Mr. Clothier was associated with A. Reyrolle and Company for more than 34 years.

TIMOTHY A. J. HAYES (A'32) director of the Boston Police Signal Service, Boston, Mass., died April 14, 1938. Mr. Hayes was born in Boston, January 11, 1882 and attended Franklin Union (Boston). From 1901 until 1911 he was associated with the Holtzer-Cabot Electric Company, Brookline, Mass. In the latter year he resigned to become director of the Boston Police Signal Service, a position he held for 26 years.

Membership

Recommended For Transfer

The board of examiners, at its meeting on May 12, 1938, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Clem, J. E., electrical engineer in central station department, General Electric Company, Schenectady, N. Y.
Terry, C. A., general superintendent, electrical department, New York Power and Light Company, Albany, N. Y.
Wood, H. B., chief electrical engineer, Stone and Webster Engineering Corporation, Boston, Mass.

3 to Grade of Fellow

To Grade of Member

Keller, C. W., sales engineer, General Electric Company, Denver, Colo.
Kidd, G. B., research engineer, Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.
Lawson, F. I., engineer, Federal Power Commission, Chicago, Ill.
Lorje, Herman, statistical engineer, State Highway Department of Colorado, Denver.
Low, H. M., refinery engineer, Phillips Petroleum Company, Bartlesville, Okla.
Mason, G. U., general electrical foreman, Guntersville Dam, Ala.
Mauseau, C. M., consulting engineer, Brooklyn, N. Y.
Page, G. I., operating engineer, Southwestern Light and Power Company, Lawton, Okla.
Park, J. G., mains engineer, North Metropolitan Electric Power Supply Company, London, England.
Sanderson, D. G. P., general electrical supterintendent, Donnacona Paper Company, Ltd., Donnacona, P. Q., Canada.
Singer, F. J., telegraph switching engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
Sirotkin, G. A., draftsman, Cutler-Hammer, Inc., Milwaukee, Wis.
Smith, Frank, equipment engineer, The Teleregister Corporation, New York, N. Y.
Torrance, W. E., manager, Wolstenholme (Pty), Ltd., Johannesburg, South Africa.

14 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1938, or August 31, 1938, if the applicant resides outside of the United States or Canada.

United States and Canada

Albrighton, R. F., General Railway Signal Company, Rochester, N. Y.
Anthony, W. T., Ohio Bell Telephone Company, Cleveland, Ohio.
Armistead, R. B., 402 Cameron Street, Chattanooga, Tenn.
Asper, I. F., Atlantic Refining Company, Philadelphia, Pa.
Austin, F. M., Houston Lighting and Power Company, Houston, Texas.
Ball, M. B., Southern California Edison Company, Ltd., Bell, Calif.
Barth, A. H., Square D Company, Houston, Texas.
Beamish, R. J. Jr., Rural Electrification Administration, Washington, D. C.
Berry, T. M., General Electric Company, Schenectady, N. Y.
Blume, A. E., 22 Maple Street, Brooklyn, N. Y.
Bork, M. J. Jr., Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.
Bound, P. T., Canadian Westinghouse Company, Ltd., Hamilton, Ontario.
Brown, H. I., Freeport Sulphur Company, Port Sulphur, La.
Buchman, R. P., Ohio Bell Telephone Company, Cleveland.
Bunyan, R. P. (Member), Ohio Bell Telephone Company, Cleveland.
Caress, A. E., Loup River Public Power District, Columbus, Nebr.
Casper, C. H., Carter Oil Company, Seminole, Okla.
Cogbill, B. A., General Electric Company, Pittsfield, Mass.
Connolly, W. T., Empire Mill Company, Spokane, Wash.
Currie, G. J., Ohio Bell Telephone Company, Cleveland.
Curry, G. W., General Electric Company, Houston, Texas.
Cuthbertson, L. J., City Clerk's Office, Girard, Kansas.
D'Agostino, V. F., Western Electric Company, Kearny, N. J.
Dign, G. N., Atlantic City Electric Company, Atlantic City, N. J.
Donahue, J. J., Allis-Chalmers Manufacturing Company, Kansas City, Mo.
Doran, F. M., Donnacona Paper Company, Ltd., Donnacona, Que., Canada.
Dyer, H. R., Bethelehem Steel Corporation, Sparrows Point, Md.
Elberfeld, J., Rochester Athenaeum and Mechanics Institute, Rochester, N. Y.
Elliott, A. R., Houston Lighting and Power Company, Galveston, Texas.
Pfolliott, C. F. (Member), Associated Electric Laboratories, Inc., Chicago, Ill.
Fontaine, C. B., Jr., General Electric Company, Lynn, Mass.
Foss, E. (Member), Pacific Telephone and Telegraph Company, San Francisco, Calif.
Frederick, E. H., Allis-Chalmers Manufacturing Company, West Allis, Wis.
Gallo, J. E., 116 Grove Street, Brooklyn, N. Y.
Gawley, B. P., YMCA, Schenectady, N. Y.
Gmeiner, E. V. (Member), Citizens Light and Power Company, Adrian, Mich.
Godsey, H. H., Tishomingo County Electric Power Association, Iuka, Miss.
Gray, J. L. (Member), Citizens Light and Power Company, Adrian, Mich.
Greear, H. B., General Electric Company, Atlanta, Ga.
Guckel, H. B., New York and Queens Electric Light and Power Company, Long Island City, N. Y.
Harper, J. A., General Electric Company, Schenectady, N. Y.
Hord, D. A., Northwestern Electric Company, Portland, Ore.
Hunt, O. D., Kansas State College, Manhattan.
Ingerson, W. E., Bell Telephone Laboratories, Inc., New York, N. Y.
Inman, D. E., Westinghouse Electric and Manufacturing Company, Cleveland, Ohio.
James, R. T., Radio Station WOR, New York, N. Y.
Jamison, J. S., Jr., Virginia Military Institute, Lexington.
Jones, D. H., Bulldog Electric Products Company, New York, N. Y.
Kallenbach, G. K., New York Power and Light Corporation, Albany, N. Y.
Karr, C. L., Western Electric Company, Inc., Kearny, N. J.
Krughoff, I. F., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Leahey, E. W., Ohio Brass Company, Philadelphia, Pa.
Lee, W. M., Kelley-Koett Manufacturing Company, Covington, Ky.
Loye, P. E. (Member), Reda Pump Company, Bartlesville, Okla.
Lundell, R. H., Puget Sound Navy Yard, Bremerton, Wash.
McDonald, F. J., E. I. Du Pont de Nemours, Wilmington, Del.
Meyer, G. A., Southwestern Bell Telephone Company, Dallas, Texas.
Miller, F. J. (Member), Buffalo Niagara Electric Corporation, Niagara Falls, N. Y.
Musket, P. P., H. G. Fischer and Company, Chicago, Ill.
Myles, A. H., Electric Controller and Manufacturing Company, Cleveland, Ohio.
Nickerson, L. T., Westinghouse X-Ray Company, New York, N. Y.
Partridge, H. R., Le Carbone Company, Inc., Boonton, N. J.
Pratt, J. L., 1515 Sante Fe Building, Dallas, Texas.
Raabe, V., The Carlisle and Finch Company, Cincinnati, Ohio.
Ray, G. W., Yankee Network, Inc., Bridgeport, Conn.
Reid, L. R., Allis-Chalmers Manufacturing Company, New York, N. Y.
Robinson, H. B. (Member), Carolina Power and Light Company, Raleigh, N. C.
Roche, W. A., National Bureau of Standards, Washington, D. C.
Sandin, J. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Scheldorf, M. W., General Electric Company, Schenectady, N. Y.

Spiak, A., Interborough Rapid Transit System, New York, N. Y.
Stacy, J. D. (Member), General Electric Company, Pittsfield, Mass.
Tambling, R. L., Bell Telephone Laboratories, Inc., New York, N. Y.
Taylor, R. H., Narragansett Electric Company, Providence, R. I.
Temple, G. H., Jr., Massachusetts Institute of Technology, Cambridge.
Tesche, C. F., 816 Summit Street, Linden, N. J.
Tierney, P. V., Reda Pump Company, Bartlesville, Okla.
Troup, D. J., 512 Cafawissa Avenue, Sunbury, Pa.
Von Soreny, E., 511 East 78 Street, New York, N. Y.
Waddington, C. V. (Member), Kansas Gas and Electric Company, Wichita, Kans.
Whelpley, E. K., Bureau of Engineering, San Francisco, Calif.
Wolff, R. S., Connecticut Light and Power Company, Waterbury, Conn.
Wright, W. D., Indiana Bell Telephone Company, Indianapolis, Ind.
Zambell, H. G., 1009 Weschler Avenue, Erie, Pa.

Total, United States and Canada—84.

Elsewhere

Atkins, J. W. (Member), Octavius Steel and Company, Ltd., Calcutta, India.
Franks, H. B. S., Hull Corporation Electricity Department, Ferensway, Hull, England.
Horn, J. G., A Reyrolle and Company, Ltd., Hebburn-on-Tyne, England.
Hunter, A., British Thomson-Houston Company, Ltd., Rugby, Warwicks, England.
Oldham, C. A. (Member), Weston Electrical Instrument Company, Ltd., Enfield, Middlesex, England.
Patell, R. J. R. (Fellow), Parsi Technical and Industrial Institute, Majura Gate, Surat, India.

Total, elsewhere—6.

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

(A) MANUAL of PHYSICAL MEASUREMENTS. By A. Zeleny and H. A. Erikson. Sixth edition. New York and London, McGraw-Hill Book Company, 1937. 237 pages, diagrams, charts, tables. 8 by 6 inches, cloth, $2.25. An outline of laboratory experiments for university courses in general physics.

DIFFERENTIAL and INTEGRAL CALCULUS. 2 volumes. By R. Courant, translated by E. J. McShane. Revised edition. New York, Nordemann Publishing Company, 1937. Diagrams charts, tables 9 by 6 inches, cloth volume 1, 616 pages, $5.00; volume 2, 682 pages, $7.00. The first volume corresponds to a beginning course. Volume II completes the study of functions of several variables and multiple integrals, continues differential equations, and takes up the calculus of variations and complex variables.

ATM (Archiv für Technisches Messen), Lieferungen 75–77, September–November 1937. Munich and Berlin, R. Oldenbourg. Illustrations, 12 by 8 inches, paper, 1.50 rm. each. Three numbers of a monthly publication containing classified articles covering various types of apparatus and methods for technical measurements.

ADVANCED CALCULUS. By W. B. Fite. New York, Macmillan Company, 1938. 399 pages, diagrams., tables, 9 by 6 inches, cloth, $5.00. Assuming familiarity with the basic operations of calculus, discusses functions of more than one variable, indefinite, infinite, and multiple integrals, various types of series, and applications to geometry.

VDE VORSCHRIFTEN. Berlin, Verband Deutscher Elektrotechniker, 1937. Diagrams, tables, charts, 9 by 6 inches, paper, apply. Supplements to the book of standards issued by the Society of German Electrical Engineers, giving new or revised regulations. The subjects covered are high-voltage a-c apparatus, electric heating apparatus, heavy-current overhead lines, antennas, the testing of insulators, and electric railroads.

MATHEMATICS for ELECTRICAL STUDENTS. By H. M. Keal and C. J. Leonard. Second edition. New York and London, John Wiley & Sons, 1938. 225 pages, illustrations, 7 by 5 inches, cloth, $1.60. Intended for industrial workers, trade school and technical high school students.

(The) LOW VOLTAGE CATHODE-RAY TUBE. By G. Parr. London, Chapman & Hall, 1937. 177 pages, illustrations, 9 by 5 inches, cloth, 10s. 6d. (obtainable from Allan B. Du Mont Laboratories, 542 Valley Road, Upper Montclair, New Jersey). Intended to give an insight into the cathode-ray tube and its technique to those who use it in work in some branches of science. The construction and operation of the tube, focusing and performance, Lissajous' figures and time bases are discussed. Various applications of the tube to radio engineering and other industries, television and photography are described.

LIGHT, Principles and Experiments. By G. S. Monk. New York and London, McGraw-Hill Book Company, 1937. 477 pages, illustrations, 9 by 6 inches, cloth, $5.00. Textbook and laboratory manual for the advanced study of geometrical optics, classical physical optics, and the more recent extensions of physical optics dealing with the origin of spectra, the interaction of light and material media, and the effects on that interaction of external electric and magnetic fields.

LIGHT, PHOTOMETRY and ILLUMINATING ENGINEERING. By W. E. Barrows. Second edition. New York and London, McGraw-Hill Book Company, 1938. 445 pages, illustrations, 9 by 6 inches, cloth, $4.00. Contains revised chapters on light sources, illumination calculations, and interior and street lighting and new chapters on gas and vapor lamps, lighting for recreations and sports, and the lighting of highways and airways.

(The) J. & P. TRANSFORMER BOOK. By S. A. Stigant and H. M. Lacey. Seventh edition. London, Johnson & Phillips, Ltd., 1937. 916 pages, illustrations, 9 by 6 inches, cloth, 6s. 6d. Deals with principles, specifications, connections, windings, tests, grounding, protection, and transformer oil, with diagrammatic and mathematical explanations.

INDUSTRIELLE ELEKTROWÄRME, Edited by Wirtschaftsgruppe Elektrizitätsversorgung. Teil 3: WO WIRD ELEKTROWÄRME MIT VORTEIL ANGEWENDET. Berlin, Arbeitsgemeinschaft zür Förderung der Elektrowirtschaft, 1937. 116 pages, illustrations, 8 by 6 inches, paper, 1 rm. Tables of the electric heating processes and equipment which may be used advantageously in various industries.

HANDBOOK of CHEMISTRY and PHYSICS. Edited by C. D. Hodgman. Twenty-second edition. Cleveland, Chemical Rubber publishing Company, 1937. 2,069 pages, tables, 7 by 5 inches, cloth, $6.00; students' edition, $3.50. This reference work has undergone the customary annual revision. About 50 pages have been added, and revisions and corrections made throughout the book, to bring the information up to date or present it more conveniently.

Great Britain. Department of Scientific and Industrial Research. ILLUMINATION RESEARCH Technical Paper No. 20. The USE of COLORED LIGHT for MOTOR CAR HEADLIGHTS. London, His Majesty's Stationery Office, 1937. 32 pages, tables, 10 by 6 inches, paper (obtainable from British Library of Information, 270 Madison Ave., New York, $0.30). A report on the relative desirability of white and colored headlights on motor cars.

ENGINEERING LAW. By R. E. Laidlaw and C. R. Young. Toronto, University of Toronto Press, 1937. 380 pages, tables, 9 by 6 inches, cloth, $4.00. A presentation of those phases of law that impinge in some manner on the acts, duties and liabilities of the engineer. Not intended as a legal text, but presents facts concerning contracts, specifications, industrial disputes, patents, company organization, and questions in connection with boundaries, surveys, and other technical matters. The references are to Canadian and English law reports.

ELETROWÄRMETAGUNG BERLIN, 5 June 1936 in Marmorsaal des Zoologischen Gartens, veranstaltet von der Wirtschaftsgruppe Elektrizitätsversorgung und Wirtschaftsgruppe Elektroindustrie. Berlin, Arbeitsgemeinschaft zür Förderung der Elektrowirtschaft, 1937. 100 pages, illustrations, 12 by 8 inches, paper, apply. A collection of papers presented at a joint meeting of the Wirtschaftsgruppe Elektrizitätsversorgung and the Wirtschaftsgruppe Elektroindustrie, on electric furnaces.

EISENLOSE DROSSELSPULEN. By J. Hak. Leipzig, K. F. Koehler, 1938. 316 pages, illustrated, 10 by 7 inches, cloth, $6.00. Designed to be a "compendium of methods" for the practical man as well as a textbook for electrical engineering students. Covers basic measurements of current, resistance, potential difference, electromotive force, inductance, capacitance, and power, and describes industrial meters, instrument transformers, calibration, determination of wave form, and cable testing.

ÉLECTRICITE et MAGNÉTISME. By G. Jochmans and F. Descans. Brussels, A. De Boeck; Paris, Librairie Polytechnique Ch. Béranger, 416 pages, diagrams, tables, cloth, 150 Belgian francs. A textbook for mechanical- and electrical-engineering students. Section I, on general theory, covers fields, forces and applications in electrostatics, magnetostatics, and electromagnetism, as well as electric currents and induction phenomena in general. Section II treats the application of electrical theories to electrical apparatus.

HOCHSPANNUNGSTECHNIK. By A. Roth. Second edition, edited by A. Imhof. Vienna, Julius Springer, 1938. 624 pages, illustrated, 9 by 6 inches, cloth, 39 rm. This discussion of high-voltage technique includes the properties of electric fields and a description of materials of high dielectric strength used in high-voltage work. The properties of insulating oils and air in an electric field are considered, as well as of oil and air in connection with solid materials.

HOW to FILE BUSINESS PAPERS and RECORDS. By A. Chaffee. New York and London, McGraw-Hill Book Company, 1938. 166 pages, illustrated, 8 by 6 inches, cloth, $2.00. Discusses in detail filing systems and their operation, filing routines and filing equipment, showing the advantages of certain types which make them particularly valuable in various specific cases.

HOW to KEEP ACCOUNTS and PREPARE STATEMENTS. By E. A. Saliers. New York, Ronald Press Company, 1938. 481 pages, charts, tables, 8 by 5 inches, cloth, $3.00. Intended for those who wish a practical understanding of accounting, but lack time or opportunity for a formal course of instruction.

INDEX to ASTM STANDARDS and TENTATIVE STANDARDS as of January 1, 1938. Philadelphia, Pa., American Society for Testing Materials, 1938. 119 pages, 9 by 6 inches, paper, gratis. Contains both a classified index and a numerical list of all standards as of January 1, 1938; these standards cover specifications, test methods, and definitions as adopted by the Society.

PRINCIPLES of RADIO. By K. Henney. Third edition, New York, John Wiley & Sons, 1938. 495 pages, illustrated, 8 by 6 inches, cloth, $3.50. In this edition, as in the earlier ones, the intent is to provide a book useful for independent study as well as for classroom use.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Transactions

Papers and Discussions Comprising Pages 295–358 of the 1938 Volume

Test and Operation of Petersen Coil on 100-Kv System of Public Service Company of Colorado

By W. D. HARDAWAY MEMBER AIEE W. W. LEWIS MEMBER AIEE

THE HISTORIC Shoshone-Denver transmission line of the Public Service Company of Colorado connects the Shoshone Hydro Plant with Denver and serves important loads in the Leadville and Idaho Springs districts in Colorado (figure 1). The line traverses mountainous country for most of its length, crosses the Continental Divide three times (figure 2), and is badly exposed to lightning. The design and construction work on the line was begun in 1906 and 1907, making this line the pioneer in its voltage class. Conductor spacing and tower clearances are very close in comparison with modern standards, and although progressive improvements have been made, the operating record of the line shows an average of 60 tripouts per year, of which 42 are chargeable to lightning.

Tapping this line at Leadville is a wood pole H-frame line supplying the Climax Molybdenum Company at Fremont Pass and the Empire Zinc Company at Gilman. Since this line is an integral part of the Shoshone-Denver system, operating records of both lines have been added to give the performance record shown in table VI, and the combined five-year average is 69.8 tripouts per year, of which 50.8 are chargeable to lightning.

The Shoshone-Denver line is a single-circuit line approximately 154 miles long with conductors horizontally arranged on steel towers. The conductors vary in size from 1/0 to 4/0 and are spaced 10 feet $4^1/_4$ inches to 10 feet 8 inches apart. A short section at the Denver end (2.22 miles) is on wood H-frames with 12-foot conductor spacing. The Leadville-Gilman tap, 30.5 miles long, is on wood H-frames with 13-foot conductor spacing. The average height of the conductors at the towers is approximately 40 feet. The line has no overhead ground wires with the exception of the 2.22 miles of H-frame line at the Denver end, which has one overhead ground wire.

Transpositions in both the Shoshone and Gilman lines are irregular, and were installed to accommodate occasional telephone parallels, rather than to balance charging current. For example, one conductor of the Shoshone line occupies the center position for 68 of the total 154 miles of line.

During recent years rapid growth of the mining load in the Leadville and Idaho Springs areas, served by these lines, has thoroughly justified steps toward improvement in service. The two obvious methods, overhead ground wires with effective tower grounding, or expulsion protective gaps, were investigated, but did not appear to apply, due to limitations imposed by the design of the existing towers. The additional structural loading of overhead ground wires appeared excessive, and the close tower clearances made successful application of expulsion gaps very difficult. The installation of a Petersen coil

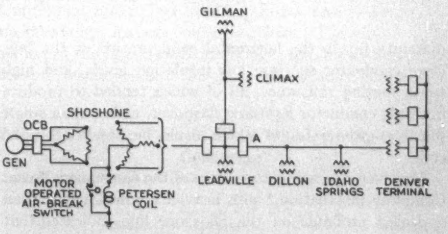


Figure 1. One-line diagram of system as normally connected

appeared to be a possible solution, and was particularly attractive as its cost estimated at considerably less than that of either ground wires or gaps.

One apparent difficulty was that the line operates normally with appreciable corona loss, as the conductor is relatively small and the average elevation above sea level is 9,000 feet, with portions exceeding 13,000 feet (figure 2). Corona loss current, of course, is not compensated for by the coil. Also it was believed that the coil should be located at the center of the line to provide more accurate average tuning for faults at any point. The only neutral transformer point available was at Shoshone at the end of the line, so the cost of a grounding bank for intermediate location at Leadville or Dillon would have materially increased the cost of the project. Another

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4. For all numbered references, see list at end of paper.

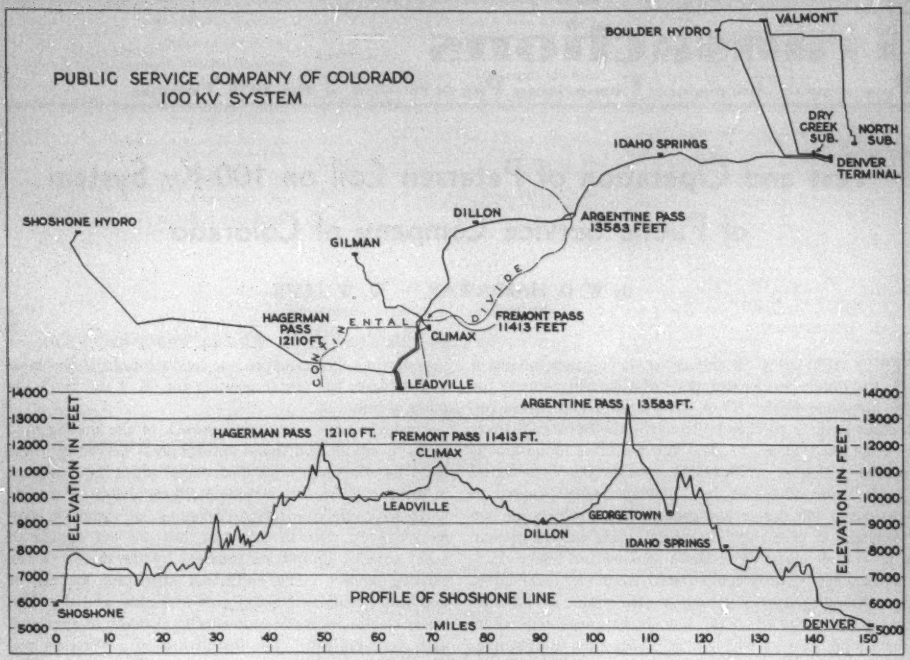

Figure 2. Map and profile of system

difficulty lay in the horizontal configuration of the line, close conductor spacing, low insulation levels, and high tower-footing resistance, all of which tended to produce multiple conductor lightning flashover, rather than single phase-to-ground faults which could be handled by the coil.

However, operating experience of the Consumers Power Company installation,[4] with heavier corona current than appeared probable on the Shoshone line, indicated that the corona problem was not particularly serious. Also, the Maine tests and Hunter's theoretical work,[5] indicated that a coil tuned for a fault at any point on a line would be in tune for faults at all other points on the line. This knowledge then permitted the selection of Shoshone for the coil location.

The problem of multiple-conductor flashovers still remained. Operating records were not very definite, but indicated that somewhat more than 50 per cent of the faults relayed out as phase-to-phase troubles. It appeared probable that some of these originated single phase-to-ground and developed into phase-to-phase faults before tripping. It appeared, therefore, that the coil would have a chance to extinguish some 50 per cent of the faults, and the installation appeared to be worth while on this basis. Furthermore, work was already under way on reconductoring and reinsulating portions of the line for mechanical reliability, which permitted increasing the normal suspension-string flashover distance from 30 inches to 38 inches, also a relatively inexpensive scheme of tower grounding or counterpoise was devised which would greatly reduce tower-footing resistances, and thereby the number of multiple-phase flashovers.

Under these conditions it appeared that a Petersen coil might initially quench up to 50 per cent of line flashovers, with the possibility of handling 75 per cent of the faults after the tower grounding and reinsulation work were completed. This was definitely economic, as no other scheme available approached this percentage of service improvement per dollar of investment.

Description of Petersen Coil

In the fall of 1936 some tests were made with the neutral isolated at Shoshone. A fault was placed on one conductor at Denver, each phase being grounded in turn, and the average of the three readings gave 123 amperes to ground at 95,000 volts line-to-line. With one conductor grounded at Leadville the charging current to ground was about 138 amperes at 95,000 volts line-to-line. Finally, a test was made on the Shoshone-Leadville section isolated from the remainder of the system. Extrapolating the results for the whole system gave 101 amperes charging current to ground at 95,000 volts line-to-line.

The Petersen coil as finally designed was rated 193

amperes for 10 minutes. The arrangement of the windings is such that there is practically a uniform voltage distribution throughout during transient conditions. The coil is insulated for the standard high potential and impulse tests for the 69-kv class (leg voltage of 115 kv). A shunting Thyrite resistor is installed inside the tank and designed to limit transient overvoltages to a safe value for the coil insulation.

Figure 3 shows schematically the arrangement of the coil and shunting Thyrite resistor. Ten taps are provided on a ratio adjuster for tuning and to take care of contemplated future extensions of the line, also disconnection of portions of the present line for maintenance.

Table I gives the approximate reactance values for the various taps, also the current rating for the three terminal tap connections. Based on an assumed value of 120 amperes for the present line from the preliminary tests previously mentioned, the coil will take care of a range of line from approximately 100 miles on the 855-ohm tap to 300 miles on the 285-ohm tap.

Figure 4 is an exterior view of the coil, showing the handwheel for adjusting the taps. Figure 5 is an interior view, showing the assembled core and coils and the shunting Thyrite resistor.

The coil was received in April 1937, and installed as shown in figure 1. It will be noted that the coil is installed with a stick-operated disconnect for isolation, and with a motor-operated air-break switch for by-passing the coil and solidly grounding the neutral. Although not so equipped initially, this motor-operated switch is now equipped with a timing relay which automatically closes the switch at the end of the pre-set time interval (approximately three minutes). The timer is controlled by a current relay in the Petersen coil lead, so that phase-to-ground faults not cleared by Petersen coil action are, at the end of three minutes, converted into single phase short circuits and the faulty section is relayed out.

During the period of April 21 to May 1 tuning and other tests were made on the system with the Petersen coil in circuit.

Tuning Tests

Figure 1 is a one-line diagram of the system as normally connected. All of the tests unless otherwise stated were made with this connection.

The coil was adjusted or tuned with the system in two

Table I. Petersen-Coil Taps

Tap Number	Terminal Tap I		Terminal Tap II		Terminal Tap III	
	Ohms	Amperes	Ohms	Amperes	Ohms	Amperes
I	855	64.3	794	69.3	738	74.5
II	740	74.3	705	78.1	663	83.0
III	675	81.5	640	86.0	602	91.3
IV	620	88.8	587	93.7	547	100.5
V	570	96.5	530	103.8	485	113.3
VI	515	106.8	475	115.7	431	127.5
VII	468	117.5	425	129.4	382	144.0
VIII	440	125.0	395	139.2	347	158.5
IX	410	134.1	367	150.0	312	176.4
X	390	141.0	338	162.6	285	193.0

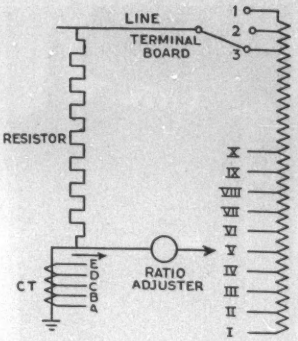

Figure 3. Schematic arrangement of coil, showing taps and shunting Thyrite resistor

different ways: First, with no grounds on the conductors. In this case the ohms were varied and the amperes through the coil read on an ammeter. When the coil and system are in tune, the amperes are maximum. The amperes flow by virtue of a residual voltage caused by the unbalance in the capacitance of the three conductors to ground. The circuit consisting of the residual voltage, the coil reactance, and the capacity reactance of the system constitutes a series resonant circuit when in tune (figure 6*a*).

Second, with a ground on one conductor, the ohms of the coil are varied and the amperes read at the line fault. When the coil and system are in tune, the amperes are a minimum, and in fact would approach zero if there were no resistance, leakage, or corona loss. The circuit consisting of the line-to-neutral voltage, the fault, the Petersen-coil reactance, and the capacity reactance of the system constitute a shunt or a multiple resonant circuit when in tune (figure 6*b*).

Table II. Tuning Petersen Coil With No Grounds on Conductors

Tap	Ohms	Petersen Coil Amperes	Petersen Coil Volts	Product Ohms × Amperes
I	855	0.6	675	513
II	740	1.0	760	740
III	675	1.3	936	878
IV	620	1.92	1,250	1,196
V	570	3.2	1,870	1,823
VI	515	4.9	2,490	2,523
VII	468	3.15	1,380	1,475
VIII	440	2.25	980	990
IX	410	1.7	680	697
X	390	1.4	528	546

Petersen coil terminal on tap I.

Tuning Tests With No Grounds on Conductors

In this test the total system was in circuit with Petersen-coil tap I connected to the line. The ohms were varied through taps I to X, and the current in the coil was read on an ammeter.

Figure 4. Exterior view of Petersen coil, showing hand wheel for adjusting taps

Table II and figure 7 give the results of the tuning tests with no grounds on conductors. In this test the maximum current was obtained on tap VI.

Tuning Tests With Ground on One Conductor

In these tests a ground was made on one conductor and the current in the fault read while the ohms of the Petersen coil were varied. Two sets of tests were made, one with a ground at Denver and one with a ground at Leadville.

Ground at Denver. In this test a ground was placed on the west phase at Denver by means of the transfer bus and an oil circuit breaker. The Petersen-coil ohms were varied and the current at the fault measured. The data are given in table III and plotted on figure 8.

Minimum current of about 22 amperes root mean square is obtained on tap VII, but the tuning is rather broad, taps VI and VIII giving only a slightly larger residual current.

Table III. Tuning Petersen Coil With One Conductor (West Phase) Grounded at Denver

Tap	Ohms	Petersen Coil Amperes	Fault Current at Denver (Root-Mean-Square Amperes)	Initial Fault Current From Oscillograph (Crest Amperes)	Product Ohms × Petersen Coil Amperes
IV	620	76	34.3	132	47,100
V	570	83	27.2	123	47,300
VI	515	90	23.1	126	46,350
VII	468	96	21.6	126	44,900
VIII	440	101	23.1	126	44,500
IX	410	107	29.0	83	43,900

Petersen-coil terminal on tap I.

Table IV. Tuning Petersen Coil With East Conductor on Gilman Tap Grounded at Leadville

Tap	Ohms	Petersen Coil Amperes	Fault Current (Amperes)	Ungrounded Phase Kilovolts at Denver*	Product Ohms × Petersen Coil Amperes
III	675	71	39	55.9–103.4	47,900
IV	620	75	33	56.0–102.5	46,500
V	570	83	27	56.0–102.1	47,300
VI	515	90	23		46,350
VII	468	98	22.1		46,300
VIII	440	105	24.1		46,200
IX	410	113	29.5	56.7– 99.4	46,350
X	390	120	36	56.5– 99.0	46,800

* First reading before conductor grounded and second after conductor grounded. Petersen coil terminal on tap I.

Table V. Insulator Flashover at Denver Terminal

Test Number	Insulator String	Petersen Coil Tap	Fault Duration (Cycles)	Amperes Fault Crest by Oscillograph	
16–1	5 Hewlett	VII	54	154	2d loop
				31	30th cycle
16–2	7 Hewlett	VII	267*	260	1st loop
				31	30th cycle
16–3	7 Hewlett	VII	48	142	2d loop
				31	30th cycle
16–4	8 Hewlett	VII	57	148	2d loop
				31	30th cycle
16–5	7 Hewlett	VI	56	222	1st loop
				31	30th cycle
16–6	7 Hewlett	V	83	179	2d loop
				43	30th cycle
16–7	7 Hewlett	VII	Fuse blew in oscillograph control circuit		
16–8	7 Hewlett	VII	840	74	2d loop
				37	30th cycle
16–9	7 Hewlett	VI	57	265	1st loop
				31	30th cycle
16–10	7 Hewlett	IX	322		Off scale
				37	30th cycle
16–11	7 Hewlett	IV	272	222	2d loop
				56	30th cycle

* Opened by breaker.
Insulator string in test 16–4 dead end, in other tests suspension.
Petersen-coil terminal on tap I.

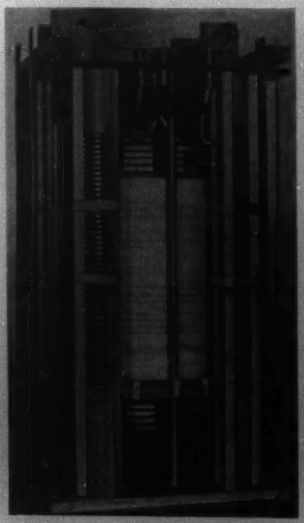

Figure 5. Interior view of Petersen coil, showing assembled core and coils and shunting Thyrite resistor

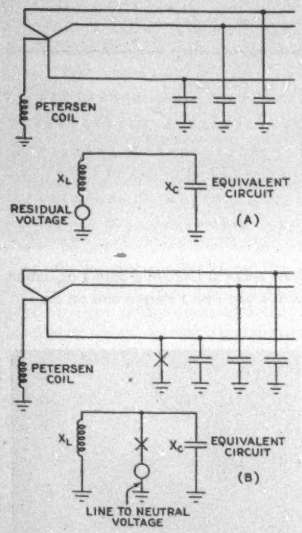

Figure 6 (left). Equivalent circuits for tuning of Petersen coil

(a) No grounds on conductors
(b) Ground on one conductor

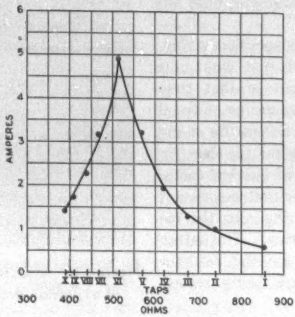

Figure 7. Tuning curve with no grounds on conductors

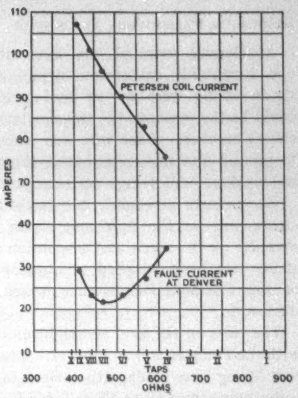

Figure 8. Tuning curve with ground on one conductor at Denver

Conductor Grounded at Leadville. For this test the line connections were as shown in figure 9. The conductor was grounded at point *G*. The data are given in table IV and are plotted in curve form on figure 10. Here again the minimum current is obtained on tap VII and is about 22 amperes.

Arcing Tests

Several sets of arcing tests were made at Shoshone, Leadville, and Denver with the Petersen coil in service. Of these the most interesting were the tests with expulsion protective gaps at Leadville and the insulator flashover tests at Denver.

Conductor Grounded Through Expulsion Protective Gaps

A series of arcing tests was made at Leadville using three 115-kv expulsion protective gaps of different bore.

The line connections were as shown in figure 9. The Leadville-Gilman line was connected to the main Leadville-Denver line at Robison switch rack. The Leadville-Gilman line was opened toward Leadville at Climax. This allowed the Climax and Gilman loads to be fed from the main line and gave a stub line from Leadville to Climax controlled through a breaker at Leadville for testing.

The tests were made at the first structure out of the Leadville substation on the stub line. This is a three-pole, wood dead-end structure.

The external gaps were set at approximately 13 inches and a fuse wire was placed across the external gap and through the tube of the expulsion protective gap. The Gilman line oil circuit breaker was then closed, thus throwing a fault on the east conductor at the point *G* through the expulsion protective gap.

Five tests were made on large-, medium-, and small-bore tubes with various settings of the Petersen-coil taps. In four tests the arc was extinguished in 0.5 cycle or less and in the remaining test in two cycles. In all cases the current interrupted was considerably under the minimum rating of the tube. In general the arc and the report were rather mild. Figure 11 is one of the oscillograms taken during these tests.

Table VI. Tripout and Flashover Record of the Shoshone-Denver Line for Five Years 1932–1936 Inclusive, and Portion of 1937

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Average number of tripouts, Shoshone-Denver line and Gilman tap, years 1932–1936, inclusive	1.8	0.6	2.6	2.0	6.4	7.6	26.8	15.4	3.0	1.4	1.2	1.0	69.8
Portion of above caused by lightning	0	0	0	0	4	7.0	24.4	14.0	1.2	0	0.2	0	50.8
Tripouts, 1937	1	2	2	1	10	8	8	2	0	1			
Petersen-coil operations, 1937					0*	7*	14	10	3	1			
Total flashovers, 1937	1	2	2	1	10*	15*	22	12	3	2			
Per cent of flashovers extinguished by Petersen-coil operation					0*	47*	64	83	100	50			

* Period of preliminary operation.

Insulator Flashovers at Denver

At Denver terminal one five-unit suspension string, one seven-unit suspension string, and one eight-unit strain string were set up and arranged so that they could be thrown onto the transfer bus by means of an oil circuit breaker. Fuse wire was placed across the string to ground and this ground fault thrown on the bus by the breaker. All strings were composed of Hewlett disks.

Eleven tests were made, one on the five-unit suspension string, one on the eight-unit strain string, and the remainder on the seven-unit suspension string. This latter string has been adopted as standard for the sections of the Shoshone-Denver line which are being reconductored.

The tests on the five- and eight-unit strings were made with the Petersen coil on tap VII. The tests on the seven-unit string were made with various taps on the Petersen coil ranging from IV to IX. Table V gives the important data in regard to these tests.

Figure 12 shows the arc on the five-unit suspension string, with the Petersen coil on tap VII. The arc lasted 54 cycles. The exposure was for the full duration of the arc.

Figure 13 shows a one-fiftieth-second exposure of a typical arc over the seven-unit suspension string. In this particular test the Petersen coil was on tap V and the arc lasted 83 cycles.

During these tests there was practically no wind blowing. The small current in the arc would cause very little heating and consequent blowing and elongation of the arc. It is probable that these two circumstances together allowed the arc to persist from three-fourths of a second to 14 seconds in one case. Under lightning conditions there will usually be a wind, and the arc will probably snap out on an average in less time than in some of the tests.

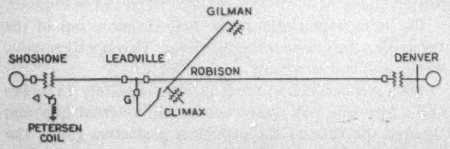

Figure 9. Line connections for arcing and tuning tests at Leadville

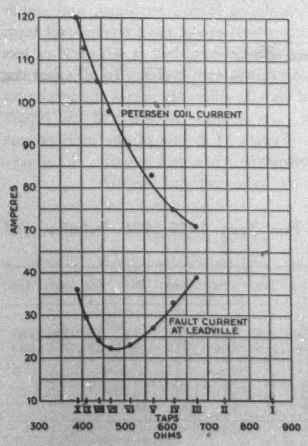

Figure 10. Tuning curve with ground on one conductor at Leadville

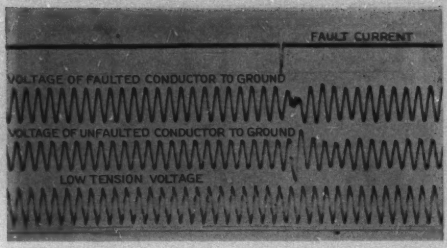

Figure 11. Oscillogram taken at Leadville during operation of expulsion protective gap with Petersen coil on tap I

Figure 12. Flashover of five-unit suspension string at Denver. Petersen coil on tap VII (test 16–1). Exposure for full duration of arc

An examination of the insulator units showed no damage to the porcelain or hardware as a result of these tests. There was no noticeable effect on the station lights nor any disturbance on the system with the exception of the ground-return telegraph circuit, which parallels the transmission line on the same right of way. This was disturbed in all of the arcing and tuning tests by induced voltage and circulating current. Figure 14 is a typical oscillogram taken during these tests.

Operating Experience

The coil was placed in service on May 1, 1937. From this date until July 1 may be considered as a period of preliminary operation. During this time unsuccessful attempts were made to work out relaying ideas at Leadville. It was hoped that an arrangement could be made which would select the faulty section of line and start a timer, which would disconnect the faulty section if the ground

fault proved to be permanent, and was not cleared by Petersen-coil action. This idea proved not feasible with the equipment available, and was abandoned after some tests. Also, later operation has indicated that such a set-up, even if successful, would be of doubtful value, as the number of cases of trouble not cleared by coil action or normal phase relaying will probably be less than one per year.

An attempt was then made to arrange the ground relaying at Leadville so that it would be inoperative while the coil was in service but would be operative with the coil by-passed and the Shoshone neutral solidly grounded. This was readily successful on the Denver breaker at Leadville, but the relays on the Shoshone breakers there gave so many faulty operations that they are now kept blocked in normal operation and are manually made operative only when the Petersen coil is by-passed.

During the period of preliminary operation weak points on the system insulation were being discovered and eliminated. Two such cases involved flashovers on the Leadville transformers, which resulted in erratic relaying and interruptions.

By the first of July these difficulties were fairly well ironed out and the operation since then appears to be normal. It should be noted, however, that reconductoring, reinsulation, and tower-grounding work on the line has been progressing, and no doubt affects the operating results.

Figure 13. Flashover of seven-unit suspension string at Denver. Petersen coil on tap V (test 16–6). Exposure one-fiftieth second

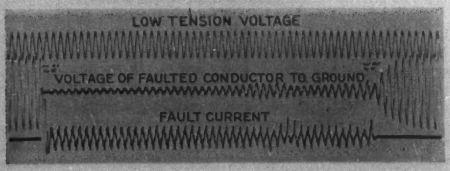

Figure 14. Oscillogram taken during flashover of seven-unit suspension string at Denver (test 16–3). Petersen coil on tap VII

Coil operation has been detected by a recording ammeter in the coil lead at Shoshone, by an automatic oscillograph at the Denver terminal, and by the effect of the communication circuit which closely parallels the transmission line.

For reasons which are not entirely clear, coil operation in service has been much faster than its performance in the staged tests, and it seems probable that some successful operations during the preliminary period passed unnoticed.

It has not been possible to keep the oscillograph on this duty continuously and some records have been missed. Oscillograms have been obtained of 21 operations. The duration of the arc ranged from 2 cycles to 216 cycles, and averaged 40 cycles.

Since July 1 all breaker operations, with one exception, have indicated as phase-to-phase or multiple phase-to-ground faults. The exception was a five-disk insulator-string failure within an indoor substation. This arc maintained for three minutes, then the Petersen coil was by-passed and the faulted section relayed out. All other single phase-to-ground arcs have been quenched by Petersen-coil action, without system disturbance.

The shock to the system at the time of coil operation is only that caused by the sudden increase in corona loss, two to three thousand kilowatts, and is negligible. However, the private telephone and telegraph circuit which is on the same right of way with the transmission line, becomes noisy and inoperative during the period of arcing.

None of the oscillograms obtained have recorded line-to-ground voltages in excess of normal line-to-line voltage.

Table VI gives a summary of the tripout data on the Shoshone-Denver and Leadville-Gilman lines for the years 1932 to 1936 inclusive; also the tripout and flashover record for 1937, during a portion of which the Petersen coil has been in operation. Between July 1 and November 1 the coil extinguished 28 out of 39 flashovers, or about 72 per cent, without circuit-breaker operation. The tripout in October was caused by a two-phase short circuit, no ground current being indicated. The fault was attributed to wet snow unloading and crossing the conductors at a transposition tower.

Conclusions

1. The Petersen coil and system were tuned by two different methods: (*a*) no grounds on conductors, varying coil ohms, and reading current through coil, and (*b*) ground on one conductor, varying coil ohms, and reading current at fault. Theoretically these two methods should give tuning on the same tap. Practically the second method sometimes requires lower ohms, because more coil current is required to balance the ground current, which is in excess of normal under this condition. The excess ground current is caused by increased capacitance due to corona, the corona current itself, and the harmonics in the charging current.

2. With one conductor grounded, tuning was on the same coil tap for a line ground at Denver and a line ground at Leadville. This confirms the conclusion reached after the Maine tuning tests, namely, that tuning would be the same for line ground at any point on the system.

3. The actual charging current at the fault was not measured during any of the tests. Assuming that it is approximately equal to the Petersen-coil current measured with a fault on one conductor, this will be about 97 amperes. This is about 1.65 times the calculated normal charging current of the system.

4. The Petersen-coil current with a ground at Denver and one at Leadville measured about the same (96 and 98 amperes respectively). Theoretically the current with ground at Denver should be considerably smaller on account of the increased line reactance. Voltage conditions at various parts of the system may have been sufficiently different during the two tests to equalize the Petersen-coil current.

5. The combination of Petersen coil and expulsion protective gap proved to be very fast and positive. In four out of five tests the duration of the fault did not exceed one-half cycle, although the current interrupted was only a fraction of the minimum rating of the tube. This combination may be valuable in locations where numerous line-to-line faults are experienced.

6. In the arcing tests over insulators, all arcs were successfully extinguished by the Petersen coil (one fault was removed by breaker at the end of four seconds). Time to extinguish the arc varied from 47 to 840 cycles. Air conditions were very quiet during some of the tests. The operating record indicates that during lightning conditions, there is usually sufficient wind to snap the arc out much quicker than in some of the tests. The observed average arcing time of 21 operations was 40 cycles.

7. The coil has been in service since May 1, 1937. In the first two months operation, trouble was experienced with faulty relay operation and breakdown of weak points in the system. In the following four months, the coil operated successfully to extinguish all single-phase-to-ground flashovers with one exception. The percentage of all flashovers extinguished by Petersen-coil operation in these four months averaged approximately 72 per cent.

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Discussion

H. M. Trueblood (Bell Telephone Laboratories, Inc., New York, N. Y.): Mr. Hardaway and Mr. Lewis state that none of the oscillograms have shown line-to-ground voltages in excess of normal line-to-line voltage. These are presumably the 21 oscillograms from the automatic oscillograph at Denver, which I assume is a magnetic oscillograph. The period of time covered by these observations is of course rather short. It is therefore interesting to recall[1] that in a series of 166 similar records extending over two years on one of the systems listed in table I of another paper,[2] the sound phase voltage to ground recorded by a magnetic oscillograph was less than normal line-to-line voltage in about 90 per cent of the cases.

There has been occasional skepticism regarding the reliability of the magnetic oscillograph for work of this sort, i.e., the recording of dynamic overvoltages at times of ground fault. Recent work of this nature in which the Joint Subcommittee on Development and Research has been participating indicates that such skepticism is hardly warranted. We have been finding that the magnetic oscillograph, with string vibrators tuned to about 3,000 cycles per second, appears to be quite a dependable piece of apparatus. It has been found to give good checks—within a few per cent on the average—with an automatic cathode-ray oscillograph, the tendency being apparently for the cathode-ray oscillograph to read slightly lower than the magnetic oscillograph.

It seems surprising that the observed coil current, as reported by Messrs. Hardaway and Lewis, should have been as much as 65 per cent in excess of the calculated normal charging current of the system, although this observed figure checks quite well with the empirical rule given[3] for medium voltage systems. Using 97 amperes as the charging current for the 187-mile system at 95 kv line voltage, the direct capacitance between one phase-wire and ground figures out to be about 0.0084 microfarad per mile. While data for an exact calculation of this capacitance from Maxwell's coefficients are not at hand, we estimate, from data for a somewhat similar system, that this figure of 0.0084, which presumably takes account of corona capacitance, is not more than 20 per cent above the theoretical value, without allowance for corona. I would be glad to learn the authors' views regarding this apparent discrepancy, which of course may have some simple explanation.

We infer, from a European publication, that an allowance of 10 per cent or so is considered about right in Europe (for a 100-kv system) for the various uncertain factors in capacitance calculations mentioned[3] exclusive of corona.

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2. Some Engineering Features of Petersen Coils and Their Applications, E. M. Hunter. AIEE Transactions, volume 57, 1938, page 11 (January issue).

J. R. North and F. Von Voigtlander (The Commonwealth and Southern Corporation, Jackson, Mich.): This paper presents in a very concise manner the results of the tests made in connection with the application of a Petersen coil to a 100-kv system. It is of particular interest to us in view of the similar tests and studies made in 1931 when considering the application of Petersen coils to a section of the Consumers Power Company's 140-kv isolated-neutral system. The Colorado and the Michigan Petersen-coil systems have somewhat similar characteristics.

The Colorado system which constitutes a total line mileage of about 185 miles is subject to very severe lightning exposures. It is located in a very high altitude, mountainous region where both the earth resistivity and the contact resistances are undoubtedly very high. The combination of these factors, coupled with the exposure to lightning storms of considerable intensity, probably contributes to the large number of trip-outs, averaging 38 trip-outs per year per 100 line miles. With the modernization of the line by adding more insulation, reconductoring with larger conductors and installing the counterpoise in addition to the Petersen coil, the number of trip-outs per year on the line should be reduced greatly.

The method of tuning the coil with and without faults on the line conductors is identical with the method followed during the Michigan tests, and corresponding conclusions are reached. Referring to our paper, "Petersen Coil Tests on 140 Kv System," presented at the winter convention in January 1934, it will be noted that the results of our tests definitely show that tuning of either one or both of the coils was not affected by the location of the fault nor by the particular conductor faulted. This fact was thus demonstrated long before the Maine tests (mentioned in conclusion number 2), although the complete mathematical proof of this fact may not have been worked out at that time.

Under "Operating Experience," the authors advised that bypassing the Petersen coil for the condition of a permanent fault,

thereby operating the system essentially with a solidly grounded neutral during this period, was successful on the Denver breaker at Leadville, but not on the Shoshone breaker there; therefore, the relays on the Shoshone breaker at Leadville are kept blocked in normal operation and are manually made operative only when the Petersen coil is by-passed. Relaying by short-circuiting the Petersen coil during times of sustained faults has proved quite successful on the 140-kv system of the Consumers Power Company so that some question arises as to what the limitations of this method of operation were found to be in the Colorado installation. Was it due to the fact that with a ground fault on the Shoshone line section the relays at Leadville would only have charging current from the other sections to operate them?

It would be interesting to have explained the control for the coil by-passing switch and the relaying for sustained ground faults on the Colorado system, particularly for such faults between Leadville and Shoshone.

The statement is also made under the heading "Operating Experience" that none of the oscillograms obtained have recorded line voltages in excess of normal line-to-line voltage. In order to obtain maximum voltages on the system as described, with the Petersen coil located at Shoshone, a ground fault should be applied to one phase of the 100-kv system at that point, the maximum voltages appearing at the distant end of the line, at Denver. Test results under this condition of maximum voltage are not reported. Calculations which we have made and later substantiated by field tests show that line-to-ground voltages of as much as 130 per cent of normal line-to-line voltages cannot only be obtained, but can reasonably be expected in extensive systems, even though the system be equipped with a properly tuned saturating-core Petersen coil.

H. P. Sleeper (Public Service Electric and Gas Company, Newark, N. J.): Why is a Petersen coil like a French telephone? Because it required 20 years' use on the Continent to introduce it to the country. In retrospect this seems rather odd, particularly in view of the excellent operating results reported abroad. On the other hand it should not be forgotten that the Petersen coil was tested experimentally in this country as long ago as 1921 and found wanting as judged by United States standards of operation (see paper by Conwell and Evans, AIEE TRANSACTIONS, February 1922, volume 41). However, the present perfected device is a far cry from the experimental model tested by Conwell and Evans and does not have the drawback of sharp tuning characteristics and the predilection to series resonance of the early design. The iron core with its broad-top tuning curve permitting detuning of the system up to 25 per cent seems to have overcome the main theoretical difficulty. The saturation of the iron core and the presence of a surge suppressor across the windings prevent the propagation of high voltages throughout the system; this latter phenomenon being the most serious practical difficulty reported by the early investigators. But the device is not yet perfect and in spite of the glowing results reported by Hardaway and Lewis the time is not yet here when the operating engineer can prescribe the Petersen coil as an antidote for all ills that can befall the operation of a modern high-voltage power system. In this writer's opinion the reported result of 72 per cent correct Petersen coil operation seems optimistically high and it would seem that the sample of operation in this case is yet too small to give accurate data which can be used generally as a criterion of expected operating results over the wide range of operating conditions presented by the various voltages, types of pole and tower line construction, terrain grounding conditions, and many other possible variables that exist here as compared with similar practice abroad. The problem presented by the all-wood-pole line is an admittedly difficult hurdle for the Petersen coil and one which will unquestionably reduce the per cent of effective operation of this device. That is not to say that the Petersen coil should not be economically applicable to that type of system, but it will require the tempering of one's expectations of close to 100 per cent operation for this device.

However, while the Petersen coil may not be the ultimate solution, it does seem to the writer that it is at least the arrow that points the direction to a new phase of high-voltage transmission system operating psychology. The practice of relaying out a faulted member of a power system is a practice universally used in this country today and has been since such operation began. This is the doctor's method of cure by amputation. But surely it is more advanced psychology to cure the patient by palliative doses rather than by operation. The same psychology applies to the maintenance of service on power systems. Why relay out a defective unit if the fault can be removed without disconnecting it from service? This might be called the method of fault removal versus fault disconnection. The superiority of the former system over the latter is unquestionable. That it cannot at this time be attained 100 per cent in no wise reflects on the soundness of the new psychology. Neither is the method of fault disconnection 100 per cent effective, and frequently its efficiency is zero per cent from a maintenance of service standpoint. Furthermore, the ultimate economic effect of the new method will always exceed that of the old since theoretically no duplicate service is now required since no disconnections will occur. Of course this is a practical fallacy, but it is undeniable that a higher degree of service should be rendered by equal facilities, and an equal degree with fewer facilities. Obviously there is some point of economic balance to be worked out in the practical use of this theory.

I don't think that the Petersen coil is by any means the ultimate answer in the application of this new psychology of power system operation. Rather it is merely a sample, or introduction. It is inherently limited to the problem of one-phase-to-ground faults. This means that its theoretical efficiency is at once limited to some value between 25 to 90 per cent, depending upon many factors. Hence, the remaining 10 to 75 per cent of faults must still resort to the old method of treatment, namely, fault disconnection. But is it beyond the bounds of conception that phase-to-phase short circuits cannot be similarly treated? It is not, of course, because it is being done today with expulsion tubes. Hence, although it may not be economical, it is possible. It does not seem unreasonable to assume that it will be done in the not too distant future by this or some other means which is well within the limits of economical feasibility for more or less universal application.

Looking forward a bit, it seems probably that the Petersen coil as we now know it will be further perfected, or maybe it will be superseded by some brain child yet unborn. Likewise the phase-to-phase problem will probably be similarly solved economically by some perfection of existing devices or others not yet developed. But, whatever form they may take, it is the writer's belief that they will merely further justify the psychology of fault removal which has been demonstrated and practically effected by the Petersen coil. And regardless of what the form may be, or where perfected, it is hoped that it will not take operating engineers in this country another 20 years to acknowledge recognition.

J. G. Hemstreet (Consumers Power Company, Jackson, Mich.): The paper by Messrs. Hardaway and Lewis, dealing with the application and operating experience of a Petersen coil on the 100-kv system of the Public Service Company of Colorado, is of particular interest to us, since the conditions are quite similar to those on the Petersen coil section of the Consumers Power Company's 140-kv system. The 100-kv system in Colorado is not quite as long as the Consumers coil section, nor does it operate at as high a voltage. Also, there are two Petersen coils in operation on the 275-mile section in Michigan.

With the thought that the operating experience over a seven-year period with the two coils on the 140-kv system would be of interest and of value in this discussion, we are summarizing it in table I of this discussion.

It will be noted that during the six-year period when automatic oscillograph records were available, 94 per cent of the line-to-ground faults were cleared without breaker operation, whereas only four per cent of the short-circuit faults were cleared without breaker operation. Of the total faults, both during the six-year period and also throughout the total period of seven years, 72 per cent of all types of faults have been cleared without breaker operation and

Table I. Petersen Coil Operation on Consumers Power Company's System

	Six-Year Period, 1931 to 1936, Inclusive, With Automatic Oscillograph		Sept. 24, 1936, to Dec. 31, 1937	Seven-Year Period Through 1937	
	Number	Per Cent	(Number)	Number	Per Cent
Number of faults					
Due to: Lightning	219	88	44	263	85
Sleet	3	1	1	4	1
Other causes	28	11	14	42	14
	250		59	309	
Line-to-ground faults	129				
Cleared without breaker operation	121	94			
Cleared with breaker operation	8	6			
Short circuits	45				
Cleared without breaker operation	2	4			
Cleared with breaker operation	43	96			
Not definitely determined	76				
Cleared without breaker operation	58	76			
Cleared with breaker operation	18	24			
Totals all types	250		59	309	
Cleared without breaker operation	181	72	42	223	72
Cleared with breaker operation	69	28	17	86	28

only 28 per cent required automatic sectionalizing of the faulted section.

It is interesting to see that this 72 per cent is the same as the experience in Colorado, as indicated in the paragraph immediately preceding the heading "Conclusions" of the paper by Messrs. Hardaway and Lewis.

We should also like to point out that during our tests, some of the arcs persisted for a considerable period. The actual operating experience with the Petersen coils has been somewhat better than that obtained during the field tests.

W. C. DuVall (University of Colorado, Boulder): In company with Professors Palmer and Eastom of the electrical engineering staff of the University of Colorado, I had the pleasure of witnessing the retuning of the Petersen coil of the Public Service Company of Colorado on the night of January 9, 1938.

If one witnessed this with the idea of seeing a spectacle, keen disappointment was in store; however, if it was viewed as an engineering achievement it was a keen delight. An arc that lasts for only two cycles is not much to see. I feel that enough has not been said about the slow recovery voltage of the faulted conductor. Oscillograms show that it takes about ten cycles for the voltage to reach normal. This gives ample time for the ionized air to dissipate and the insulation to recover to its normal value before normal voltage is reached. This slow recovery is inherent with the Petersen coil and seems to have its maximum time of recovery for the point of sharp tuning.

In the case of the Public Service Company tuning was found to be on tap number 6. Oscillograms taken between the faulted conductor and ground on taps above and below number 6 showed an oscillation, one beat was present. On taps number 5 and number 8 the voltage was found to pass through normal at about one cycle increasing and reaching a maximum overshoot at about three cycles, then decay and reach normal voltage in about ten cycles. This overshooting, or oscillation, is not present for sharp tuning. By using an automatic oscillograph and finding the tap that produces no beat is a third method of tuning and is probably the most accurate method. The reasons for this slow recovery voltage and the beat are rather complex. In returning to normal conditions the faulted conductor has its potential raised from a low value (zero in most cases) to phase voltage, conductor to ground. The clear conductors have their potential lowered from line voltage to ground, to phase voltage to ground. The charge on the faulted conductor is raised from zero to normal, the charge on the sound conductors lowered from that produced by line-to-line voltage to that produced by phase voltage.

If this automatic slow voltage recovery could be incorporated into into circuit breakers they could be redesigned more effectively. One more point: the *A. E. G. Progress*, April 1929, page 113, states that in Germany secondary cable networks of potentials as low as 3,000 volts have been successfully protected by the Petersen coil. Not to protect against surges produced by lightning necessarily, but faults produced by accidental grounding.

The relative cost of Petersen coils versus relays and circuit breakers warrants some real investigation on the application to cable networks especially at voltages from 13,000 to 30,000. This is particularly apropos in the face of some recent serious cable failures.

R. E. Hellmund (Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.) [**Editor's Note:** This discussion covers also "Some Engineering Features of Petersen Coils and Their Application," E. M. Hunter, *EE, Jan. '38, Trans. p. 11–18*]: Various grounding means, particularly the Petersen coil, were the subject of extended discussion at the International Conference on Large Electrical High-Tension Systems in Paris last June. Unquestionably a rather strong case was made for the Petersen coil, and as a result even greater use of this coil may be expected in Europe in the future. Although I discussed some of the solutions common in this country, such as grounded neutral with high-speed relays and breakers, the use of deion gaps on the line, and the use of quickly reclosing breakers, it was obvious that the Petersen coil was favored by a large majority of those present at the meeting. However, regardless of this, subsequent inspection of apparatus and power systems did not convince me that the Petersen coil is the best solution under all conditions. For example, it is difficult for me to believe that the addition of Petersen coils to a well-sectionalized double line with high-speed relay systems and high-speed breakers would be justified economically. This would make it necessary to use transformers with a neutral fully insulated against ground, which, particularly in the case of tap-changing transformers, would lead to complicated and expensive designs. The European arrangements of this kind, while highly ingenious, did not impress me favorably as compared with the American transformer designs for solidly grounded neutral.

There was also a good deal of evidence that in some applications of Petersen coils the problem of lightning protection by arresters leads to considerable difficulty. It seems that during an arc to ground, which according to the papers presented today may last a great many cycles, overvoltages occur which are hard to handle by available designs of arresters. This has led to the practice of applying arresters with a greater margin wherever the insulating level of the system makes this possible. Frequently, however, the insulating level of European lines seems to be so low as to force close application of lightning arresters and consequent frequent damage to arresters. Nevertheless, there are a great many places, especially for medium voltages, where the Petersen coil can be applied to good advantage and its use should be given serious consideration in this country. As experience with the Petersen coil is accumulated for conditions prevailing here, a gradual increase in its use may be expected.

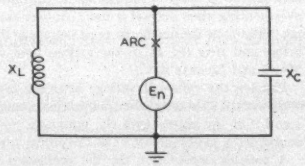
J. R. Eaton (graduate student, University of Wisconsin, Madison) [**Editor's Note:** This discussion covers also "Some Engineering Features of Petersen Coils and Their Application," E. M. Hunter, *EE, Jan. '38, Trans. p. 11–18*]: Mr. Hunter, in his paper, makes several statements regarding arc extinction on a Petersen-coil system, which on first examination appear contradictory. However, by a more careful analysis of the factors determining fundamental frequency recovery voltage across the arc, the statements are found to be in general quite correct. Refer to figure 1 which is figure 6 of the Lewis and Hardaway paper. Those authors have demonstrated that this circuit represents at least approximately the equivalent Petersen-coil system. It may be noted that this is a parallel reso-

nant circuit energized by a generator connected to it through an arc. When properly tuned, the frequency of the resonant circuit is equal to that of the generator. Suppose the arc were to go out at current zero, as it always does at least until reignition occurs. The recovery voltage will be zero, because the voltage between the arc electrodes will be zero and will theoretically remain zero indefinitely. That is, the resonant circuit will continue to oscillate and the voltage of the condenser-inductance junction would be forever equal to, and in phase with, that of the line-to-neutral generator. Suppose next, that as in figure 2, resistance R_1 is inserted in series with X_L, and R_2 in parallel with X_C. When the arc goes out the resonant circuit will no longer oscillate indefinitely but will die down exponentially with time. The voltage across the electrodes will again be the vector sum of neutral and condenser voltages or

$$e = E_n \sin wt - [E_n \sin wt]\epsilon^{-at}$$

where a is dependent on the losses in the resonant circuit, and the rate of rise of recovery voltage will be

Figure 1



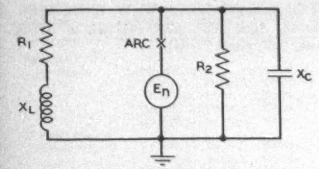


Figure 2

$$\frac{de}{dt} = E_n[w \cos wt - w\,\epsilon^{-at} \cos wt + a\epsilon^{-at} \sin wt]$$

At $t = 0$ this becomes

$$\frac{de}{dt} = a\,E_n \sin wt$$

Suppose again that the tuned circuit has a frequency slightly different $(w - b)$ from the generator frequency—that is, the Petersen-coil system is slightly out of tune. At the instant the arc goes out at current zero, the voltage appearing across the electrodes will be approximately

$$e = E_n \sin wt - [E_n \sin (w - b)\,t]\epsilon^{-at}$$

The recovery voltage is now dependent on both a and b.

Although apparently ignored in the past, a rather complete record of recovery voltage appears at the end of every oscillogram showing a ground fault on a Petersen-coil system. It may be observed that following the clearing of the arc, system conditions do not return to normal immediately, but change gradually as the transient in the oscillating current dies out. As the losses in the circuit determine the rate of decay of the transient, it is possible to calculate from the rate of decay alone, the ratio of the in-phase uncompensated current to the quadrature compensated current.

A study of recovery voltage on the basis of the above approach, shows quite strikingly that arc interruption is much more probable on a Petersen-coil system, whether in tune or not, than would be found on a simple *LR* or *CR* circuit having arc current of the same magnitude and phase position. Moreover, it shows that for best operation Petersen coils cannot be located at any point on the system but should be located near the major part of the system capacitance, rather than being tied through a long transmission line of high ohmic resistance. Any factor which tends to decrease the time constant of the oscillating system will result in higher rates of rise of recovery voltage and hence less probability of arc extinction.

W. D. Hardaway and **W. W. Lewis:** Doctor Trueblood expresses surprise that the observed Petersen-coil current was as much as 65 per cent in excess of the calculated normal charging current of the system. Measurements on five systems, varying in voltage from 33 to 140 kv, have shown the ratio of Petersen-coil current to calculated normal charging current to range from 1.75 to 2.15, with a fair average of about 1.9. The normal charging current is based on the capacitance to neutral, which is susceptible of fairly accurate calculation. The capacitance to ground is more difficult to calculate accurately, as it depends on the location of the ground plane, the presence of ground wires, the proximity of trees, the increase in apparent conductor diameter due to corona, etc. Tests on a 110-kv system consisting of one horizontal circuit with two overhead ground wires showed the average measured zero-sequence capacitance (capacitance of one conductor to ground when all three conductors are in multiple) to be 1.5 times the average calculated zero-sequence capacitance. The average measured zero-sequence capacitance of one vertical 110-kv circuit with one overhead ground wire was 1.2 times the average calculated zero-sequence capacitance. The calculated capacitance in this case was based on the actual geometrical relations at the towers, assuming the ground plane to be at the earth's surface, but with no allowance for trees, connected apparatus, or influence of corona on conductor diameter.

Messrs. North and Von Voigtlander asked for information as to the control for the Petersen coil by-passing switch and method of relaying for sustained ground faults, particularly between Leadville and Shoshone.

The Leadville relaying, before the Petersen-coil installation, included normal directional relaying for phase-to-phase faults, which is of course still operative. Phase-to-ground relaying was made selective between the Shoshone and Denver breakers by the magnitude of the fault current. That is, the residual or zero-phase-sequence current at Leadville for faults on the Denver side was much higher than for faults on the Shoshone side, and a satisfactory selectivity was obtained by blocking the Shoshone breaker trip when residual currents exceeded a definite value. When the current was below this value, a residual voltage relay was permitted to make a contact and trip the Shoshone breaker.

With the Petersen coil in service, it was not possible to find current values for the blocking relays which would be inoperative during the successful Petersen-coil operation, but which would still function when the coil was by-passed. The ground relaying on the Denver side has continued to function satisfactorily. The phase-to-phase relays will trip the Shoshone breaker under the condition of a single-phase-to-ground fault on the Shoshone side with the coil by-passed, although they are slower than is desirable.

The control of the coil by-passing switch is very simple. A current transformer in the Petersen-coil ground lead actuates an overcurrent relay, which starts a timer, set to make contact at the end of three minutes. The timer contact controls the closing circuit of a motor-operated air-break switch. Opening this switch is a manual operation. The performance of this air-break switch appears to be satisfactory, and the installation was much less expensive than an oil switch would have been.

As to the question in the last paragraph of the discussion concerning line voltages: As there are no high-tension breakers at Shoshone, we were not able to make tuning or grounding tests at that point. However, we made tuning tests at Leadville by throwing a ground on one conductor and during these tests we read the voltage at Denver on one of the ungrounded phases. These readings showed that the voltage jumped from approximately 56–57 kv to approximately 99–103 kv. In actual operation during the summer of 1937, the automatic oscillograph at Denver was in service with

one vibrator on a potential transformer, which was connected between one high-tension conductor and ground. Oscillograms of 21 operations did not show any voltages in excess of normal line-to-line voltage, as mentioned in the paper.

Mr. Hemstreet gives some very interesting information in regard to the operation of the Petersen coils on the Consumers Power Company's system. In regard to his statement that the actual operating experience has been somewhat better as to duration of the arcs than obtained during staged tests, this checks with the Colorado experience. In the staged tests of May 1937 insulator strings were flashed over in 11 cases at Denver, the arcs continuing from 48 to 840 cycles. In a similar set of tests made at Denver in January of this year, consisting of ten insulator string flashovers, the arcs lasted from one to 688 cycles. In actual operation during the 1937 season in 21 cases the duration of the arc varied from two to 216 cycles with an average of 40 cycles. The increased persistence of the arc during staged tests is probably partly due to metallic particles and vapor from the fuse wire used to start the arc. On the other hand, during actual operation in lightning storms there is usually considerable wind, while in both sets of staged tests the air was quiet.

Tests of May 1, 1937

Test	Tap	Ohms	Maximum Crest Voltage of Grounded Conductor	
			Before Arc	After Arc
16–11	IV	620	100	123
16–6	V	570	100	104
16–9	VI	515	100	98
16–5	VI	515	100	100
16–8	VII	468	100	104
16–2	VII	468	100	104
16–1	VII	468	100	104
16–4	VII	468	100	104
16–3	VII	468	100	104
16–10	IX	410	100	119

Tests of January 9, 1938

Test	Tap	Ohms	Maximum Crest Voltage of Grounded Conductor	
			Before Arc	After Arc
1	IV	620	100	120
2	V	570	100	109
2A	V	570	100	113
3	VI	515	100	100
3A	VI	515	100	100
7	VI	515	100	100
4	VII	468	100	105
5	VIII	440	100	112
5A	VIII	440	100	113
6	IX	410	100	127

We are glad that Professor DuVall noticed and commented on the slow rate of recovery of the voltage at the faulted conductor and the overshooting when the coil is under- or over-tuned. The accompanying tables show the maximum crest voltage of the grounded conductor before and after the arc at the various taps, for the staged tests of May 1 and January 9.

Plotting the values of voltage after the arc as ordinates against ohms or taps as abscissas, we obtain curves similar to those of figures 8 and 9 of the paper, with the minimum points at tap VI. This undoubtedly indicates tap VI as the proper tap for tuning.

A possible explanation for the oscillation and overshooting of the voltage of the faulted conductor after the arc breaks is contained in a paper by one of the authors in the section headed "Arcing Tests" ("The Neutral Grounding Reactor," W. W. Lewis, AIEE TRANSACTIONS, volume 42, April 1923, pages 417–34, or AIEE *Lightning Reference Book*, 1937, pages 77–94).

Discharge Currents in Distribution Arresters—II

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TWO YEARS ago, the authors of this paper described to the AIEE a co-operative investigation by the Boston Edison Company, the Commonwealth Edison Company of Chicago, the Detroit Edison Company, the Georgia Power Company, and the General Electric Company, having as its object the determination of data relative to lightning discharge currents through distribution lightning arresters. At that time the results were based upon records obtained over a 13-month period from August 1934 to August 1935, inclusive. The object of this paper is to present the results from August 1934 to September 1937.

About 1,350 installations have been made for measuring lightning discharge currents, each installation consisting of two magnetic links supported by a wooden bracket, with the links spaced approximately three-quarters of an inch and two and one-eighth inches from the arrester ground lead in most cases. The use of two links not only permits a wider range of currents to be measured, but also indicates any reversal in the polarity of the discharge current.[1]

As described in the authors' first paper on this subject,[2] the method of measurement used is accurate within ten per cent through a range from 500 amperes to 17,000 amperes for single unidirectional waves or for damped oscillations of the type used in making the laboratory calibration. Values down to 300 amperes and up to 25,000 amperes can be estimated.

When comparing data taken with magnetic links on different systems, or even on the same system, it is recognized that since it is impossible to be sure that links are changed after each stroke, there is bound to be a certain amount of superposition of results, the magnetic link recording the highest value if there has been no change in polarity. With different systems, the method of servicing the links was somewhat different, so that in some cases the effects of several storms may be superimposed. The effort has been to change the links after each storm in so far as this could be done economically.

Data concerning the four systems being studied are given in table I. The classification of circuits as urban or rural is entirely arbitrary. Those which have more than 12 customers per mile are classed as urban, all others as rural.

Table I. Distribution of Surge-Crest-Ammeter Installations

Operating Company	Line Voltage	Transformer Connection	Rural or Urban	Surge-Crest-Ammeter Installations: Present Number	Installation, Years to Date	Number of Records Obtained
Georgia Power Company	120–240		Rural	19	15	19
	2,300	Delta	Urban	37	70	72
	6,900	Delta	Rural	36	165	151
	11,500	Delta	Rural	81	300	192
	11,950	Gr. Y	Rural	97	305	155
Detroit Edison Company	4,800	Delta	Urban	78	119	11
	4,800	Delta	Rural	350	1,004	419
	24,000	Gr. Y	Urban	12	39	39
Commonwealth Edison Company	4,000	Gr. Y	Urban	324	1,002	169
	12,000	Gr. Y	Rural	20	39	16
	20,000		Rural	0	2	0
Boston Edison Company	4,000	Gr. Y	Urban	298	976	365
				1,352	4,036	1,608

Results

To secure an over-all picture of the results, it is perhaps best first to examine all of the data from all of the companies, later breaking it down for a somewhat more detailed study.

Magnitude of Current

Figure 1 shows the distribution of the discharges as to current magnitude, without respect to polarity or to the circuit involved. These results are based upon 1,608 records from 4,036 installation-years. These figures include 95 records and 145 installation-years in which current to ground was measured, but not through individual lightning arresters, as for instance on secondary neutral ground connections or in the common ground lead of three-phase arresters. Twelve records exceeding 25,000 amperes were obtained. These are included in the curve, but since their magnitude is not known, the curve is not plotted beyond 25,000 amperes.

This curve shows that 50 per cent of the discharge currents through arresters may be expected to be at least as great as 1,300 amperes, while only 1.2 per cent may be as large as 20,000 amperes. Although it is rather dangerous to extrapolate data of this sort, it would appear that an occasional record of 30,000 to 40,000 might be expected. A more accurate measure of the duty on an arrester is obtained if the results from the rural and urban locations are considered separately.

Polarity of Current

In view of the work already done with respect to lightning currents through transmission line towers,[3]

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K. B. McEachron and W. A. McMorris are research engineers with the General Electric Company at Pittsfield, Mass.

1. For all numbered references, see list at end of paper.

considerable interest attaches itself to the polarity of the currents measured. Of the total of 1,608 records obtained, 1,011 were negative and 597 were positive. Based on the expectancy curves of figure 2, negative currents of 5,000 and 15,000 amperes may be expected 3.7 and 3.5 times as frequently as positive currents of the same magnitude. From the point of view of the performance of the arrester, either in protecting transformers or in keeping itself out of trouble, the polarity of the impulse is of no consequence. However, it appears to be quite firmly established that direct strokes of lightning reaching transmission line towers[3] are about 95 per cent negative, although the polarity of strokes to open country is believed to be more evenly divided between positive and negative. There is laboratory evidence that the so-called cone of protection around a grounded point is greater when the point is positive than when negative. If this can be applied to natural lightning, negative cloud discharges to positive transmission lines would concentrate on the lines a much higher percentage of the total discharges than if the polarities were reversed. As the line becomes lower in height, the positive and negative discharges would approach each other in frequency of occurrence, assuming equal numbers of positive and negative discharges over the terrain involved. This is of course somewhat of a speculation, but does seem to have some foundation.

Comparison of Urban and Rural Results

In figure 3 are plotted expectancy curves for all urban and all rural arrester discharge currents. These results indicate that the rural arrester will be called upon to discharge a current of 500 amperes about twice as often as an urban arrester; at 15,000 amperes the rural arrester must discharge about nine times as often as the urban arrester.

From the standpoint of duty on the arrester, these results indicate that one rural arrester out of 50 installed will discharge a current of 15,000 amperes or more each year, while but one out of 450 urban arresters will be called upon to discharge a current of 15,000 amperes or more in any one year.

The number of records per installation-year for all arrester installations is 0.39, while the corresponding values for rural and urban installations are 0.51 and 0.28. On the basis of equal numbers of installation-years in rural and urban locations, 81 per cent more records of all current magnitudes are obtained on rural circuits. These values are based upon the average of the results for a large number of measuring locations. The severity at certain installations with greater than average exposure may be considerably greater.

Discharge Currents Through Urban Neutral and Phase Arresters

Since the magnetic-link installations in Boston are equally divided between six-kv phase arresters and three-kv or six-kv neutral arresters, a direct comparison between neutral and phase arresters may be obtained from the Boston data. These circuits were originally installed as 2,400/4,160-volt three-phase four-wire ungrounded neutral circuits, but the neutrals have since been grounded without making any changes in the arresters used. One hundred sixty-six phase-arrester current records and 189 neutral-arrester records were obtained. The number of installation-years in each case is 488, giving 0.34 records per installation-year for the phase arresters and 0.39 for the neutral arresters. For all practical purposes, it can be stated that the number of records is the same;

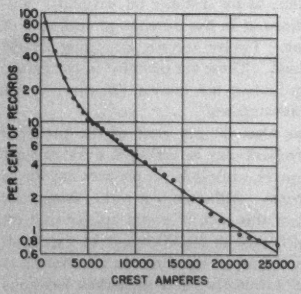

Figure 1. Summary of all records

Half of the 1,608 records were of currents of less than 1,300 amperes. Curve shows per cent of discharges whose magnitude was at least as great as indicated

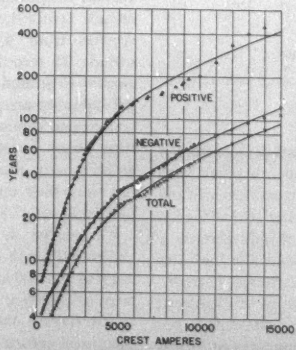

Figure 2. Comparison of 597 positive and 1,101 negative records from 4,036 installation-years

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

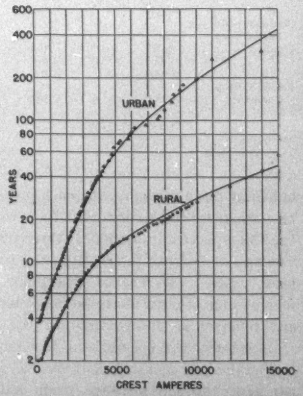

Figure 3. Comparison of 588 urban and 925 rural records from arrester ground leads

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

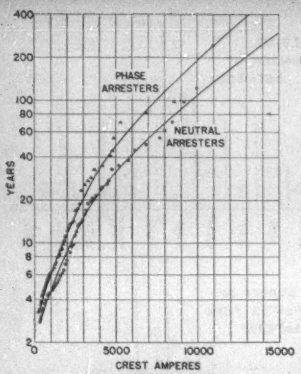

Figure 4. Comparison of 166 records from six-kv phase arresters and 189 records from three-kv neutral arresters on circuits of the Boston Edison Company

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

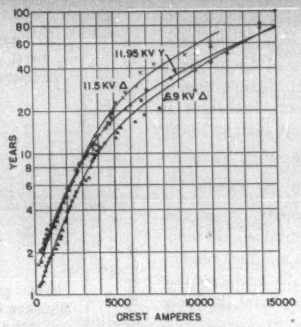

Figure 5. Comparison of results from Georgia Power Company circuits of different voltage ratings

151 records from 6.9-kv circuits
192 records from 11.5-kv circuits
155 records from 11.95-kv circuits

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

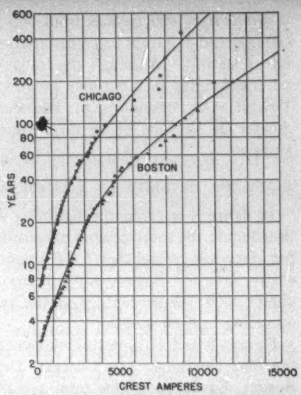

Figure 6. Comparison of 123 urban records from the Commonwealth Edison Company of Chicago and 365 urban records from the Boston Edison Company

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

however, from figure 4 there seems to be a definite tendency for the current to be 20 to 30 per cent greater through the neutral arrester. Some difference in current would be expected in those cases where the two arresters are effectively in parallel, and the discharge current may divide between them according to their resistance. Because of their lower average rating, the neutral arresters would have lower resistance and would pass higher current in such cases.

Effect of Circuit Rating

There seems to be no definite effect of circuit rating upon arrester discharge currents, although as shown in figure 5 there is a slight tendency for the lower rated arresters to carry a current of a given value more frequently. All of the data in this figure come from rural installations of the Georgia Power Company, all within the same state and presumably with about the same degree of exposure. The differences between the curves are too small to be more than an indication of what to expect, since a great many unknowns influence the results.

Effect of Location Upon Number of Records

For a given locality, the number of records per month seems to vary almost in proportion to the number of storms in that locality. However, as between localities, the correlation is not good.

A comparison between the results of 976 installation-years in Boston and 874 installation-years in Chicago is interesting. In Boston the currents are through three-kv and six-kv arresters used as neutral and phase arresters, while in Chicago the results are based on current measurements through three-kv phase arresters. Three hundred and sixty-five records were obtained in Boston compared to 123 obtained in Chicago. The expectancy curves of figure 6 indicate that a current of at least 10,000 amperes will occur in Boston about three times as often as in Chicago, in spite of the fact that an average of 15 thunderstorms per year were reported by weather bureau stations near Boston, and 45 per year at Chicago during the period of the investigation. These results seem to indicate that as far as records of arrester discharge currents are concerned, some other factor than number of storms per year exerts a major influence. A similar difference was found for the first 13 months of the investigation, and it was suggested by the authors that the difference might be due largely to difference in exposure. In Chicago the shielding is undoubtedly much more effective than is the case in Boston where the installation might more properly be classed as suburban. The difference is possibly due in part to less frequent checking of the magnetic links in Chicago. Most installations there were checked only once a year. However, since most of the links remained unmagnetized even at the end of that period, it does not appear likely that there was much superposition of records.

From the above it follows that the prediction of arrester currents upon the basis of thunderstorm data, in a locality where current measurements are not available, is not likely to lead to a very satisfactory result. The 20-year isokeraunic map[4] of the Weather Bureau indicates about 40 storm days per year in Chicago compared to 20 in Boston.

A comparison may also be made between the records obtained on rural circuits in Georgia and Detroit. Figure

7 summarizes 490 records from 765 installation-years in Georgia and 419 from 1,004 installation-years in the vicinity of Detroit. Although the frequency of discharges of all magnitudes is 1.5 times greater in Georgia than in Detroit, the frequency of high-current discharges is greater in Detroit, being three times as high as 15,000 amperes.

Lightning Severity by Months and by Years

In figure 8 is given the lightning severity by months, based upon the total number of records obtained, the number of records greater than 5,000 amperes, and the thunderstorm data for Boston and Chicago. In each case the charts show the percentage of the year's total lightning occurring in each month.

Figures 9 and 10 give the relative severity by years in the four locations; i.e., Georgia, Detroit, Chicago, and Boston, based upon the total records and those above 5,000 amperes. Values are given in per cent of the overall average for the four locations for the period of the investigation. Here again it should be remembered that links were checked less frequently in Chicago and this may have resulted in some decrease in the apparent severity.

Relative Severity in Different Locations

The greatest number of records per installation (figure 9) was obtained in Georgia each year but 1937, the average

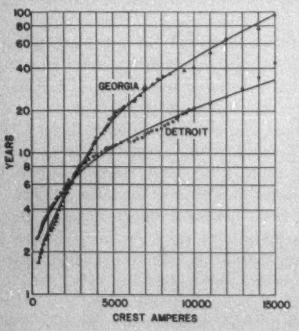

Figure 7. Comparison of 490 rural records from Georgia Power Company and 419 rural records from the Detroit Edison Company

Curves show the number of years that may be expected to elapse for each discharge of at least the magnitude indicated, through any one arrester

to date being about double that of the next highest, the Detroit Edison Company. For records above 5,000 amperes (figure 10) the Detroit Edison Company has the highest average. Although the Georgia records are twice as great in number as the Detroit records, above 5,000 amperes the Detroit records are about 30 per cent more numerous. A similar situation exists between Detroit and Boston, the average number of records being approximately equal, yet the number of records above 5,000 amperes being about four times as great in Detroit as in Boston. This seems to indicate that lightning strokes are more severe in Detroit or else the line construction is such that a higher level of line insulation is

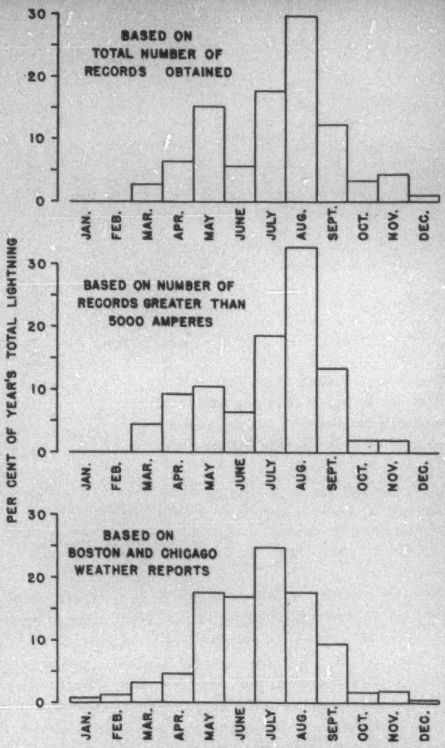

Figure 8. Relative lightning severity by months

maintained. The Commonwealth Edison data cannot be used to good advantage in this comparison, because the circuits are so predominantly urban.

There seems to be a persistent feeling among operating men that although the storms are less frequent in the Middle West than in the South, the strokes are more violent and do more damage. The Detroit data tend to support this contention, as far as the severity of strokes is concerned. Damage to apparatus was, however, much more frequent in Georgia.

Arrester and Transformer Failures—Fuse Blowings

There has been much speculation as to the performance of lightning arresters when subjected to natural lightning currents of different values, with regard to the protection offered and the effect on the arrester itself. Figure 11 shows the operating record of arresters for all four systems. With 3,787 installation-years involved, the arrester failure rate is 0.66 per cent per year. These data of course include arresters of all makes and ages. Exclusive of Georgia, the failure rate is 0.27 per cent per year, which is a very satisfactory record.

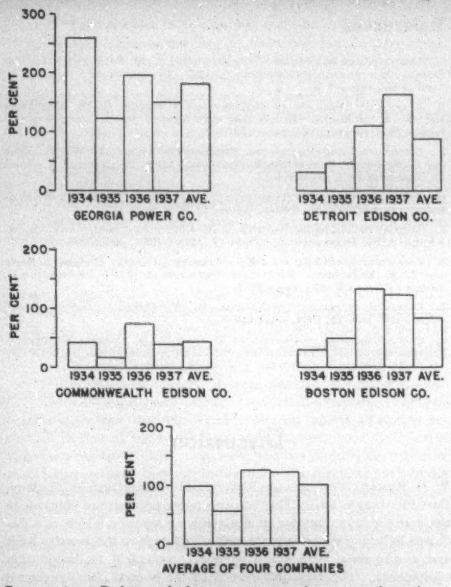

Figure 9. Relative lightning severity by years based on total number of records obtained

Values shown for 1934 and 1937 cover only a part of the year

There is some tendency for the failure rate of arresters per record to increase as the current increases, although this is not apparent to any extent if the Georgia data are excluded. Sixty-eight per cent of the arrester failures occurred in Georgia, despite the fact that Georgia had but 34.5 per cent of the total records.

Of the 12 records above 25,000 amperes, two are associated with one transformer failure. There were no arrester failures associated with these high currents. As to the distribution of these high currents with respect to location, one came from Chicago, two from Georgia, three from Boston, and six were obtained from Detroit.

Eighty-four per cent of the arresters under study were interconnected in 1937, but no segregation of data is attempted since the number not interconnected is too small to yield definite conclusions. Possibly the transformer failure record would have been even better than it is, if a larger number of arresters had been interconnected.

The data show 36 fuse blowings, of which 28, or 78 per cent, were reported from Georgia. There is some tendency for the percentage of fuse blowings per record to increase with increasing arrester current, but as with the arrester data, this effect is practically nonexistent if the Georgia data are excluded. This may be explained by the fact that at some of the Georgia locations, the fuses were ahead of the arresters. They would therefore be called upon to pass all impulse currents which went to ground through the arresters, and the high-current discharges may in themselves be sufficient to blow the fuses.

Of the 17 transformer failures, 13 were in Georgia giving an over-all failure rate of 0.72 per cent of the installed transformers per year, and excluding Georgia, a rate of 0.21 per cent. Why the Georgia trouble rate is higher than the others is not clear, although it is partly explained on the basis of increased frequency of lightning discharges.

Conclusions

1. Within the limits of this investigation, circuit rating seems to have but little effect upon the frequency of occurrence of arrester discharges of a given current magnitude. If any conclusion is to be drawn, it is indicated that the lower rated arresters tend to carry more current, or to carry a given current more frequently.
2. Fifty per cent of the currents measured were found to exceed 1,300 amperes, while 0.75 per cent exceeded 25,000 amperes. In the current range from 5,000 amperes to 15,000 amperes, negative currents were found about 3.5 times as frequently as positive currents. The smaller ratio of negative to positive discharges compared to measurements on transmission line towers may be due to the lower height of the distribution circuits.
3. The rural arrester must discharge currents of the

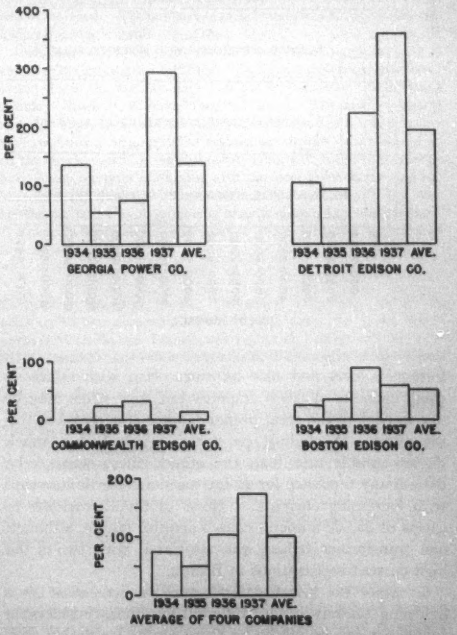

Figure 10. Relative lightning severity by years based on number of records of currents greater than 5,000 amperes

Values shown for 1934 and 1937 cover only a part of the year

order of 500 amperes twice as often as the urban arrester, while at 15,000 amperes the ratio is increased to nine to one. The rural arrester must discharge a current of 15,000 amperes or more once in 50 years and the urban arrester once in 450 years.

4. There does not seem to be any satisfactory method for translating Weather Bureau thunderstorm data into the number of arrester discharges to be expected. In a given locality, however, the variation in the number of records agrees fairly well with the variation in the number of storm days.

5. In general the largest number of arrester and transformer failures and fuse blowings occur with relatively small currents of 3,000 amperes and less. This may be due in part to the great preponderance of currents of this magnitude. Excluding one system which had a much higher trouble rate than the others, there seems to be little if any tendency for an increased arrester failure rate with increasing currents. None of the 12 currents in excess of 25,000 amperes caused arrester failure, although one transformer failure was associated with two of the high current registrations in Boston.

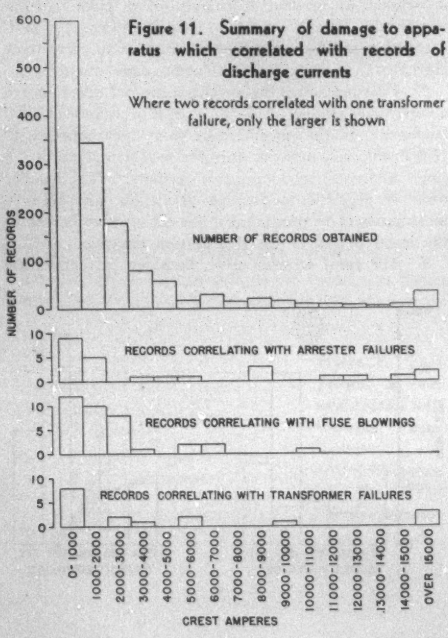

Figure 11. Summary of damage to apparatus which correlated with records of discharge currents

Where two records correlated with one transformer failure, only the larger is shown

6. Since the investigation covered a little over three lightning seasons in four different localities, considerable confidence can be placed on these results for design purposes. Proper consideration must of course be given to the circuits and localities involved, and to the limitations of the methods used in making this study.

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Discussion

W. G. Roman (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The data this paper presents are valuable to the arrester manufacturer in designing an arrester which can discharge lightning surge currents without damage to the arrester itself and at the same time afford adequate protection to distribution equipments. The arrester's record so far is good, but continued efforts should be made to improve it both in design and in the method of application.

It is interesting to note that of the 12 records above 25,000 amperes none were associated with arrester failures. This indicates that the distribution arrester has a discharge capacity sufficient to handle even the more severe lightning surges.

Can the higher trouble rate experienced in Georgia be co-ordinated with the type of protective scheme used or the ground resistance of the average arrester installation? As the authors point out, the lightning discharge frequency is higher in Georgia than on the other systems, but their trouble rate is higher than can be accounted for by this increased frequency.

The magnetic-link surge-crest ammeter has given much valuable data on lightning surge currents. A need is felt for data of this type on the duration of the surge current as well as the crest value. Has the General Electric Company any data on the type of record which would be obtained with a magnetic link inclosed in a conducting or semiconduction sheath? Currents induced in this sheath would tend to prevent the link being magnetized. On short surges this effect would be greater than on long surges of the same crest current and it might be possible to use this link co-ordinated with an unshielded link indicating crest current to give an approximate indication of the length of the surge.

I. W. Gross (American Gas and Electric Service Corporation, New York, N. Y.): The magnitude and frequency of lightning currents in distribution arresters actually measured in the field, as reported by Messrs. McEachron and McMorris, show how far short our present AIEE Standards fall in setting up standards for impulse tests of lightning arresters. The authors' paper (figure 1) shows over 40 per cent of the recorded currents above 1,500 amperes (the maximum value mentioned in the Standards); ten per cent are above 5,000 amperes and five per cent above 10,000 amperes, with maximum recorded currents of 25,000 amperes.

Certainly the users of lightning arresters want to know what degree of protection the arrester is capable of supplying at these higher currents so that they may co-ordinate, on a sound and economical basis, the arrester protective level with the apparatus it is intended to protect. In the none too distant past it must be admitted the ap-

plication of arresters for protection was more on a catalog basis of system voltage rating rather than on the basis of establishing a protective level known to be below the safe strength of the apparatus.

As more data of the type presented in this paper are obtained, including rates of voltage and current rises of natural lightning on electric systems, it is hoped our knowledge of the protective characteristics of the arrester will be extended to cover at least those conditions which are known to exist in the field.

The authors mention 36 cases of fuse blowings. I would like to ask if they can tell us the current rating of these fuses, or the approximate rating. In other words does field experience, from these tests, give any information on fuse sizes which do or do not blow under known lightning currents?

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): An essentially statistical investigation of this type gains progressively in value as the number of results accumulates. It has now reached the stage where reliable conclusions may be drawn. We feel, however, that the interpretation of some of the results is open to question.

With 976 installation-years, Boston obtained 365 records, while with 874 installation-years Chicago obtained 123 records. This was in spite of the fact that the Weather Bureau reports 15 storms per year at Boston as compared with 45 storms per year at Chicago. Most installations in Chicago were checked but once a year, while the checkings were more frequent in Boston. The fact that most of the links remain unmagnetized at the end of a year is no assurance that there was a negligible amount of superposition of records.

An excess of superposition over the amount computed, assuming the records to obey a statistical distribution, is to be expected, because, first, in a given year certain locations in a large city will be located in a larger proportion of storm centers than others and, second, due to less shielding by neighboring buildings some locations may have a considerably greater a priori probability of being struck than others.

At 22 locations in Chicago the links were checked four times during 1936; 12 records were obtained, assuming no superposition to have occurred in the short intervals between inspections. If the installations had been checked but once in 1936, it appears that only eight records would have been found. In other words, in order to obtain the correct number of records, at least 50 per cent would have to be added to the observed number as obtained on the yearly basis.

This superposition is much greater than would be predicted under the assumption that all locations were equally susceptible to lightning during 1936. The straight application of the Newton formula to the data would indicate that 1.8 records had been lost while the number actually lost was four. The data obtained in 1937 at these same 22 locations gave similar results. In this year the number of records actually lost by superposition was four times the computed number.

It is not our contention that the apparently abnormally low lightning severity in Chicago is completely to be explained by superposition of records. The effect of the better shielding conditions in Chicago, as suggested by McEachron and McMorris, may explain the balance of the discrepancy.

The highest current shown in figure 6 for Chicago, i.e., 9,000 amperes, was for an installation having standard arrester connection and $10^1/_2$ ohms ground resistance. Apparently at the time of the discharge, an old three-kva transformer failed, but the old-type arrester at this location did not fail. This is another experience showing that the arrester standards should specify a much higher current than 1,500 amperes for acceptance tests on modern-type arresters.

L. G. Smith (Consolidated Gas, Electric Light and Power Company of Baltimore, Md.): The data being collected by the authors are of considerable value in designing the lightning protection of distribution systems and determining the necessary discharge capacity of lightning arresters applied to such systems. However, in order to be of conclusive value it requires the collection of a considerable amount of data. The 1,352 installations constitute a very small sample of the total number of installations of distribution lightning arresters. It is highly desirable for more companies to co-operate so as to increase the number of installations and spread and coverage of the territory represented by these installations. However, before definite conclusions can be drawn, many more years of collection of data will be required. The industry is greatly indebted to the authors for undertaking such a valuable study.

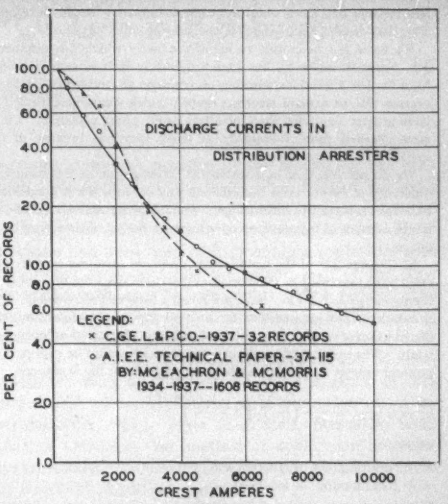

Figure 1

Last summer our company installed surge-crest-ammeter links at 150 distribution-arrester locations. As these installations were completed late in the summer, data were obtained for only two lightning storms. However, 32 records were obtained. The maximum surge amperes recorded were 6,500. Surge currents as low as 500 amperes were recorded. As a matter of interest our meagre data was plotted on the curve shown by the authors in figure 1, in order to determine how closely our data conformed with the more voluminous data collected by the authors. These two curves show remarkably close agreement for the small number of records obtained by our company. We plan to continue the collection of these data over a period of several years.

C. Francis Harding (Purdue University, Lafayette, Ind.): In addition to my discussion of the similar paper by L. G. Smith entitled "Distribution Transformer Lightning Protection Practice—II" it should be noted that the results of this statistical field analysis also confirm the predictions based upon the experimental tests of the four-span standard distribution system subjected to surge generator exposures at Purdue University under the auspices of the Public Utilities Research Commission of Chicago.

The record reported in this paper of relatively high surge currents in the arresters located on rural distribution circuits indicates that the attenuation of the wave along such circuits is not as great as anticipated and that the magnitude thereof should be more seriously considered in establishing higher current testing standards by the lightning-arrester subcommittee.

K. B. McEachron and **W. A. McMorris:** Mr. Halperin presents some interesting results based on data obtained in 1936 at 22 measuring locations, where links were checked four times during the lightning season. It is indicated that with annual inspection of links, the number of records lost by superposition would have been at least four, but the number predicted on the basis of equal exposure of all locations would have been approximately two. If only two

less records had been obtained, this discrepancy would disappear. The 1937 results were based on a smaller number of records.

We have not been able to identify exactly which measurements Mr. Halperin refers to, but they apparently include some readings from the few special installations on common ground leads, interconnection ties, or neutral arresters (gaps), which would be expected to have greater exposure than installations on phase arresters. Links were checked more frequently at these locations because of the special installations there.

We do not feel that in a statistical investigation of this nature, a difference of two or three records one way or the other is a sufficient basis for very definite conclusions. The following analysis based on a larger number of installations over a longer period of time may be of interest.

In Chicago 236 of the installations on phase arresters on 4-kv circuits have remained in their original locations since the beginning of the investigation. They have produced a total of 104 records. If it is assumed that all locations have equal exposure to lightning, the distribution of records may be calculated from the law of independent trials. The number of locations each of which would be expected to produce exactly k records may be determined from the expression

$$n_k = n \frac{m!}{k!\,(m-k)!} \left(\frac{1}{n}\right)^k \left(1 - \frac{1}{n}\right)^{m-k}$$

where

m = total number of records, and

n = total number of locations.

The actual and calculated distributions for Chicago are as follows:

k Records per Location	Number of Locations With Exactly k Records Each	
	Calculated	Actual
0	151.8	151
1	67.2	67
2	14.7	17
3	2.1	1
4	0.2	0

The agreement between actual and calculated distribution is surprisingly good. The same is true for the Detroit and Georgia records, and to a lesser degree for the Boston records. This agreement indicates that the distribution of records has not been greatly influenced by factors which have not been taken into account and therefore that no great error would result from using the theory of probability to predict the number of records lost by superposition.

When $k = 0$, the above equation reduces to

$$n_0 = n \left(1 - \frac{1}{n}\right)^m$$

solving for m,

$$m = \frac{\log n - \log n_0}{\log n - \log (n-1)}$$

This equation will permit us to estimate the number of records lost by superposition. If we let n_0 represent the total number of installations at which links remained unmagnetized after a given period of exposure, then m represents the expected total number of discharges during that period. The number of records obtained would be equal to $(n - n_0)$, so $m - (n - n_0)$ would be the number of discharges which were not recorded because of superposition. The curve in figure 2 herewith is based on this relation. It does not account for the later discharges of a multiple stroke, which are not free to discharge through any path at random, but have a very strong tendency to follow the first discharge of the series.

Several who have discussed this paper have brought out the point that the present standard AIEE impulse tests are not representative of the most severe discharges measured in service. Field data on the arresters involved in the investigation do show, however, that the

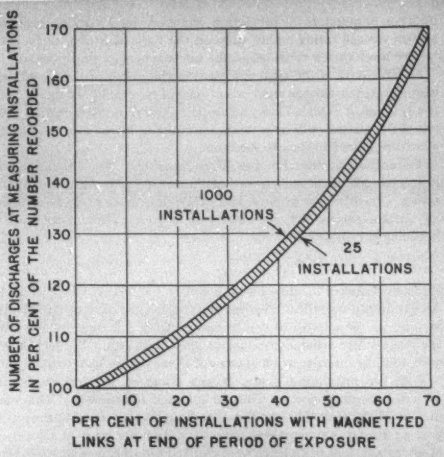

Figure 2. Effect of superposition of records on the number of discharges actually recorded, assuming that it is equally probable for any discharge to appear at any measuring installation

arresters which have the best protective characteristics on the AIEE test have given the best account of themselves under service conditions.

Mr. Gross has inquired about the ratings of fuses which were reported to be blown. These extended from two amperes up to 30 amperes. The rate of fuse blowing was higher for those locations where the fuse was ahead of the arrester, so that arrester discharge currents were carried by the fuses. Some of the fuse blowings are believed to have resulted from overloads due to secondary faults, rather than from lightning currents alone.

There is great need for more data on the duration of impulse current waves, as pointed out by Mr. Roman. We have considered the method of measurement he proposes, as well as other similar methods, for adapting magnetic links to give an approximate indication of wave fronts and duration. Laboratory tests have been made over a period of several months to determine the best constants for the sheath, and to obtain calibration data.

This method is attractive because it is so simple and inexpensive to apply. The interpretation of records is however quite complicated, and only approximate results are obtained, because of the large number of variables involved. It may prove desirable to make installations of this type, but it is hoped that other equally inexpensive methods may be developed for obtaining information more easily interpreted into accurate values for wave shape and duration.

We do not have suficiently complete data available to justify definite conclusions as to the causes of higher arrester and transformer failure rates in Georgia. Some of the ground resistances were, however, relatively high. The use of longer leads from secondary neutrals to arrester grounds may have contributed to the higher trouble rate.

We are pleased that others are undertaking investigations of this nature and that the results already obtained by Mr. Smith are in general agreement with what we have reported. The accumulation of more data will more firmly establish what duty is imposed on a distribution arrester in different types of service.

Since the scope of the investigation has been limited, it may prove more advantageous to alter it to obtain more information on the few discharge currents above the present measuring range, to include other localities or types of circuits, or to obtain information on the wave shape or duration. A given amount of work may bring greater returns to the industry if directed along these lines, than by merely continuing at the present locations with no changes.

Results of Operation of PCC Cars in Pittsburgh

By T. FITZGERALD
ASSOCIATE AIEE

THE Pittsburgh Railways Company has purchased 201 cars of the Presidents' Conference Committee type. By the middle of November 1937, there had been delivered and placed in service 140 of these cars. The new vehicles have exceeded our expectations with respect to their mechanical performance, their reception by employees, and the approval given them by the public.

The company placed its first order, consisting of 100 cars, in July of 1936. Of these, 75 units are equipped with Westinghouse motors and control apparatus, and 25 are General Electric equipped. The same distribution was made on the second order.

Prior to the delivery of any units of the first order, we obtained a sample car which we used to demonstrate to the public the superior qualities possessed by this outstanding advance in vehicle design. We operated this sample car in demonstration service from August until December, in which period we carried 25,000 passengers free, and it was inspected by uncounted thousands on the streets. This period of operation also gave our mechanical department an opportunity to study its design and to devise methods by which to cope with such difficulties as developed. The preliminary study and experience thus obtained by the mechanical group were of great value, in that they were well prepared to test the cars as they arrived, and to adjust them to give the performance of which we knew the car to be capable.

The design of the PCC car incorporates features which we in Pittsburgh had felt for a long time were essential in a trolley car if it were to compete effectively with the private automobile and the bus. The principal deficiencies of the cars we had were excessive vibration and noise; inadequate deceleration; inadequate, jerky acceleration; and unnecessary weight. We had a little speed, which we obtained by rewinding the motors on about half of our cars, which increased their power by 50 per cent and their free running speed from a maximum of 30 miles per hour to a maximum of 40 miles per hour, an increase of 33⅓ per cent. On a six-per-cent grade, the speed improvement of the higher-speed cars was 50 per cent. When the cars were converted to higher speed, we increased the braking efficiency and performed other work on them designed to make the car in general conform with its higher speed characteristics.

It will be noted that the operating characteristics of the rewound-motor cars approach those of the PCC cars, so that we are able to place both types of cars in a schedule without losing the efficiency of the new car, and with reasonable assurance of maintaining the schedule.

Delivery of our first order of cars commenced in late January of 1937. At the outset, we had to decide whether to fully equip a route with the new vehicles, or to equip the base service of the route selected, and use cars with rewound motors to supplement the service for the peak haul. We decided on the latter plan, because we could thereby get a greater coverage of the system, and also keep the new cars in service to a greater extent. If the new cars had been used to fully equip a route, the peak cars would have been idle the greater part of the time. By applying the cars to base and evening schedules only, we were able to equip ten routes with the first group, and we will equip 13 routes with the second 100 cars.

At the middle of November, we had a total of about 3,440,000 miles of operation on the first group of cars, and 60,000 miles of operation on about one-third of the second order, which began to come in during the latter part of October. Our method of application results in securing about 1,000 miles of service per week on each car, or 50,000 to 52,000 miles annually.

We have had less mechanical trouble with these vehicles than with any new car we have had on the property. We have had troubles, of course; none, however, which were fundamentally serious, or for which the engineers have not been able to devise remedies. In the light of the severe operating conditions which the Pittsburgh district offers, and the far-reaching changes in car design incorporated in the vehicle, it is to be wondered why we have had comparatively so little difficulty with them.

Evidence of how the cars are standing up in service is furnished by the weekly mileage of 1,000 miles which they are averaging. At ten miles per hour, that means they are averaging better than 14 hours of service per day, exclusive of time standing as spares, and of time required for routine inspection and cleaning.

Earlier, I indicated that noise reduction was an important advantage which we expected from the new design. The new car has advanced a long way in this regard, but it has made us acute to new noises which will have to be corrected. A short time after the cars were delivered, it was noted that a distinct and irritating rattle developed when crossing special track work, and when going over track irregularities. The source of the noise was found to be the bearings of the brake-shoe hangers on the brake-beam. Rubber was introduced into the design to eliminate the difficulty. Altogether, the noise level of the car is a tremendous improvement but it is not as good as we should seek to make it.

When we purchased the new cars we experienced some anxiety over the hypoid gears with which the cars are driven. Our experience has been such as to convince us that our fears were unfounded. So far, we have had only

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five gear failures and each was traceable to omitted lubrication which maintenance routine will overcome.

We have had no failures of resilient wheels except those which were damaged because hand brakes had not been fully released, or because the required pressure was not properly maintained on the rubber sandwiches incorporated in the wheel.

We have had little or no trouble with motor generator sets. The wear on rail brake shoes has been very slight. We feel we are getting good wearing properties out of our rail brake shoes, largely because our technicians have made the dynamic brake properly do its job. We are obtaining from four to five times the mileage on wheel brake shoes and they cost a little more than twice the cost of regular brake shoes. We originally estimated we would obtain about 60,000 miles of service from the resilient wheels of the PCC cars. Indicated wear at the present time is about 100,000 miles for one-half inch of wear, which is the limit of wear obtainable. This compares with 140,000 miles on regular wheels for two and one-half inches of wear. Due to the limited wear on shoes and wheels, there is considerably less labor required in resetting brakes.

We have had two derailments in 3,500,000 miles of operation, due to mud on the tracks, carried there by severe storms, and one derailment due to a broken propeller shaft. We have had one split switch caused by an object in the switch, and one split switch probably caused by excessive speed. I personally feel that these cars are going to hold the rails longer, not only in the sense of avoiding derailments and split switches, due to the resilient wheel, but also in the sense of demonstrating the value of rails in transit service and re-establishing the prestige of that type of service.

We have not made any changes in schedule speeds on the routes where the cars were installed, largely because the schedules were designed for and operated by the higher-speed cars which I have mentioned. The higher-speed schedules are, however, about 15 per cent better than is obtainable with the standard slow-speed cars.

Power consumption on the PCC car is, by test, about the same as that on the higher-speed car, and it is 25 per cent greater than on a standard slow-speed car. We will save considerable on heat, however, with the PCC car, over the conventional car. We use electrical space heaters on the old cars, and the new cars of course use the heat dissipated by the control resistors during acceleration and dynamic braking to heat the cars. We have ample heat in the new cars; in fact, we are receiving complaints of excessive heat, whereas the old cars are complained of as being cold, on days when extremely low temperatures prevail. We are not in position to estimate the effect of this on power consumption until we go through a winter with the new cars.

The PCC cars we have are all of the foot-control type. Although we had experimented with foot control on seven cars, it is the first time we have had a considerable number of cars of that type in operation. In qualifying trainmen on the new cars, we found that on the average about four hours of practice is all that is needed. The reaction of trainmen to the car has been universally good. They like them because of their smooth performance characteristics, the adequacy of the brakes, and the resultant ease of schedule maintenance, and because lost time can be recovered so much more easily with the new car. The only difficulty in operation so far encountered is glare in the windshield at night, particularly on wet nights. This is due to the bright interior, and we have mitigated this difficulty by various methods, such as dimming the cab lights, cutting off floor reflection, blacking the windshield frames, and on the second order of cars provision is made for a curtain which can be drawn about the operator's position.

Of course, the true measure of the new car rests in the effect upon revenues and the effect upon costs. We have seen enough of the car to lead us to feel that the costs will not be higher than with the conventional car and, if anything, the new car will produce an economy in track maintenance, power costs, and in costs peculiar to the car itself.

So far, the public response to the vehicle has been splendid. We have received many communications from patrons, who have been pleased with the improved service; and from civic and municipal groups, congratulating the company on the new vehicle. We are constantly receiving inquiries as to when the new cars will be installed on other routes in the system, which is another evidence of their popularity. The noise-reduction qualities of the new car have accentuated complaints of noise from older cars. I have for a number of years held the opinion that much of the lack of prestige of street cars was traceable to the noise attending their operation. The items of superiority of the new cars over the older cars most frequently mentioned are its quiet operation and its smooth performance.

I will now turn briefly to the patronage results on the routes where we have installed the new cars. I am sorry that we cannot speak more definitely about the increased patronage they have attracted. Further, I must confine my remarks to results on the routes on which the first 100 cars were installed, because we have had insufficient experience, up to this time, on the second group to record any patronage results.

The picture on three of the routes on which new cars have been installed has been confused by the fact that we made fare concessions at about the time the new car service was inaugurated. On certain of the routes, territory is served which is also served by other routes which do not have the new equipment, so that it is possible that certain patrons may use either route. In the studies which have been made, we have endeavored to adjust as nearly as we can for the factor of competition of the new cars with the older cars. On two routes on which the new cars have been installed and where a fare concession also was made, there has been no reduction of revenue—on the contrary, the route earnings have shown an increase. The fare reduction which was made was of substantial proportion.

It should be remembered that thus far where the new cars were installed, we previously operated higher-speed cars, which in themselves had a tonic effect upon revenues.

The new cars, of course, have provided a much improved performance and appearance, and to that we must ascribe the added traffic obtained. A property which has not speeded up its service will, in my opinion, secure the advantage of traffic stimulation from the greater speed of the PCC car. We began our program of conversion of cars to higher speed at the start of the depression, and we continued the program during the depression. We found that the routes which were equipped with the higher-speed car held their patronage better than others—an advantage, of course, which the recent installation of PCC cars does not give us in the making of comparisons.

The installation of new cars commenced on February 4, 1937. Two days later, on February 6, the rate schedule of the Pittsburgh Motor Coach Company was reduced from 25 cents cash, nine tickets for $2.00, to 15 cents cash, eight tickets for $1.00, and 20 tickets for $2.00. The routes on which the rate change took place had been originally designed to furnish a service supplemental to the rail service, and in most instances they occupied the same streets or closely paralleled rail service. It can be readily appreciated that with such a sharp reduction in fare, traffic on the busses was stimulated. Many of the new car routes have been up against this bus competition, and they have shown revenue improvements despite this unfavorable circumstance.

Data we have obtained to determine increased patronage shows that the new cars have been responsible for improvements ranging from 5 per cent to 11 per cent.

When consideration is given to the elements which affect the comparisons, such as bus competition, previous higher-speed schedule service, and installation in the spring of the year when traffic normally is on the decline, I feel that we have had a very favorable patronage response to the new car.

Our experience with the mechanical and electrical performance of the PCC cars has been better than we expected and is satisfactory. The cars have the performance to attract and hold patronage, and in my opinion they are an adequate answer to the charge of obsolescence of street railways. Continued improvement in the vehicle, which is inevitable, will, I believe, result in complete rehabilitation of the prestige of the street car as the most efficient and economical carrier where traffic demands heavy enough to justify that vehicle are encountered.

Discussion

R. E. Hellmund (Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.) [**Editor's Note:** This discussion covers also "The PCC Street Car," C. F. Hirshfeld, *EE, Feb. '38, Trans. p. 61–6*, and "Electrical Equipment for Modern Urban Surface Transit Vehicles," S. B. Cooper, *EE, Jan. '38, Trans. p. 50–6*]: The fact that the Presidents' Conference Committee car has attracted considerable attention in Europe may be of interest. Some of the visitors to the World Power Conference in 1936 had an opportunity to inspect the first Pittsburgh car and they were very much impressed not only by the technical features of the car but also by the arrangement which made its development possible. They felt that similar undertakings in Europe might be instrumental in bringing about renewed activity in electric street railways. When I visited Europe in 1937, I was surprised at the many inquiries made by the engineers regarding the PCC car, with reference both to generalities and to details, such, for instance, as the number of steps in the control, voltage per step which could be handled by the two types of control, etc.

As usual, it will for various reasons be difficult to directly apply American designs in Europe. For example, the narrow streets and sharp curves in many European cities are not suitable for a long two-truck car such as the PCC. There also seems to be some hesitancy in Europe to design motors for temperature rises and the very high speeds used in this country because experience along these lines is still lacking in Europe. Although for this reason developments may take a somewhat different course, I nevertheless believe that we can expect to see innovations in Europe which have been stimulated and influenced, at least to some extent, by the PCC car.

Operating Experiences With Gas-Electric-Drive Motor Busses

By R. H. STIER

THE Philadelphia Rapid Transit Company operates a co-ordinated urban transportation system serving the City of Philadelphia and adjacent suburban communities. The system is comprised of surface car, subway-elevated, motor bus, and trackless trolley lines. Motor-bus operation was started in September 1923, with 21 double-deck mechanical-drive busses of the "Fifth Avenue" type. At the present time a total of 323 busses are operated 12 million miles annually, and produce approximately nine per cent of the system passenger revenue. The busses operated include 138 33-passenger single-deck and 161 71-passenger double-deck gas-electric-drive busses purchased during 1925 and 1926. The remaining 24 vehicles are small-capacity 21-to-25-passenger busses, that have been purchased during the past four years.

Operating characteristics of the original 21 mechanical-drive double-deck busses, purchased in 1923, were most unsatisfactory from a passenger or transportation viewpoint. These busses were noisy and rough during acceleration, due to inherent characteristics of the clutch and transmission equipment. In order to determine means of improving the operation of these vehicles, the Philadelphia Rapid Transit Company investigated alternate drive mechanisms that could be applied to the motor bus.

It was learned that the General Electric Company had built ten double-deck gas-electric-drive busses for the Fifth Avenue Coach Company in 1904. In so far as could be ascertained operation of these vehicles was entirely successful. The experiment was abandoned, apparently due to reluctance of any of the automotive manufacturers to undertake construction of the gas-electric-drive bus, probably due to increased cost for the electric drive and limited market for motor busses.

During the interval between 1904 and 1923 the electric drive was not commercially developed, although isolated applications of the electric drive to automotive equipment were made, principally by the United States Army. Information available indicated that the electric drive offered the greatest promise of eliminating the objections of noisy and rough operation experienced with the mechanical-drive vehicle.

One of the "Fifth Avenue" type double-deck busses operated by the Philadelphia Rapid Transit Company was equipped with the electric drive. The apparatus was essentially identical to that still operated in 299 PRT busses, consisting of a separately excited four-pole generator similar to the GE 1098 machine, two series-wound variable-voltage four-pole motors similar to the GE 1079, and a simple three-position drumtype controller. Performance of the bus was improved to so marked a degree that the electric drive was specified for the 352 busses purchased by the Philadelphia Rapid Transit Company during 1925 and 1926.

During the early years of operation the usual trials and tribulations that go hand in hand with the pioneering of a new development were experienced. Operating problems were multiplied by the rapid growth that occurred in the Philadelphia Rapid Transit Company's bus operation, which was expanded from 527,000 miles in 1924 to 8,000,000 miles in 1926.

The problems were accentuated by changes in design of the vehicle, made during the early years of operation, which tended to increase the effective load on the electrical equipment. These changes included the replacement of the original 34-inch solid tires by 40-inch pneumatic tires on the double-deck busses and by 38-inch pneumatic tires on the single-deck bus; and the enclosure of the upper deck with resultant increased vehicle weight. The electrical apparatus was rebuilt to increase its capacity and improve its performance. Increased capacity improved performance of the equipment, but the basic cause of continued failure of the electrical equipment was attributed to use of noncommutating-field motors and generators. Commutator and brush wear was excessive and frequent flashover, with resultant damage to equipment, was experienced in service. After considerable study of the problem, in co-operation with engineers of the General Electric Company, methods of installing commutating field poles in the standard GE 1098 generator and GE 1079 motor were developed. Analysis of service data indicated that cost for this change would be justified in the GE 1098 generator, but it was doubtful whether the cost could be justified in the GE 1079 motor. During 1931 and 1932 the majority of the GE 1098 generators were rebuilt and commutating field poles installed. Mileage operated between reconditioning periods was increased from 32,000 for the noncommutating-pole GE 1098 generator to 107,000 miles for the commutating-pole GE 1098 generator.

Performance of the electrical equipment can be judged by analysis of maintenance expense, shown in table I. Maintenance expense for electric transmission equipment includes all costs for generators, motors, controllers, kilowatt-hour meters, and wiring. It will be noted that installation of commutating poles, during 1931 and 1932, decreased percentage of total maintenance chargeable to electric transmission equipment from an average of 17 per cent to an average of less than 13 per cent of total maintenance expense. Record of maintenance expense for these vehicles and for the electric transmission equip-

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ment, during recent years, is an outstanding achievement that can be largely attributed to the inherent advantages of the electric drive.

The Philadelphia Rapid Transit Company is now confronted with the necessity of replacing the greater portion of its bus fleet, 93 per cent of which is of the gas-electric type and has been operated between 11 and 12 years. In view of the imminent purchase of new bus equipment, the controversial question as to whether or not the electric drive should be utilized must be answered. Since 1924 extensive changes in design of clutch and transmission equipment have been made, that eliminate many of the objections to the equipment that were in part responsible for the original selection of the electric drive in 1924. Although majority of busses that have been operated are of the gas-electric type, operating experience with these vehicles is of little value in determining the type equipment best suited to the service requirements, since the vehicles are of obsolete design and construction, and since comparative service data is not available for the mechanical-drive bus. It is considered that a description of the analysis that has been made of the relative advantages and disadvantages of the electric-drive and mechanical-drive motor bus would be of greater interest than an elaboration of the operating experiences with vehicles of obsolete design.

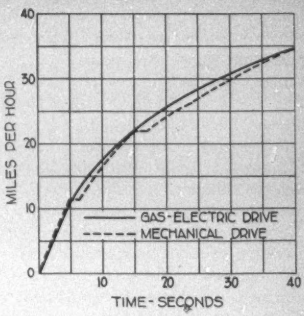
Discussion of the relative merit of the electric drive will be predicated upon its use in frequent-stop heavy-traffic urban service for which it is basically adapted. The primary problem encountered, in weighing the relative advantages and disadvantages of the electric-drive and mechanical-drive bus is to secure authentic, comparative basic data. In order to secure the fundamental information required, tests were conducted with a number of modern busses of various types. For simplification we have limited the discussion to analysis of representative results obtained from performance tests of two 35-passenger busses of identical design and construction, differing only in that one vehicle was equipped with a conventional clutch and three-forward-speed, constant-mesh transmission; the other vehicle equipped with a GE 1501 self-excited generator and one GE 1205 series-wound motor. Both busses were tested with the equivalent of a seated passenger load, the mechanical-drive vehicle weighing 21,425 pounds and the electric-drive weighing 23,050 pounds.

Table I. Maintenance Expense for Gas-Electric-Drive Motor Busses

Year	Total Maintenance (Cents per Mile)	Maintenance—Electric Transmission Equipment	
		Cents per Mile	Per Cent of Total Maintenance Expense
1926	4.60		
1927	5.50		
1928	5.04		
1929	7.29	1.17	16.1
1930	5.86	0.90	15.4
1931	5.01	0.86	17.3
1932	4.03	0.85	21.1
1933	2.71	0.28	10.3
1934	2.76	0.34	12.3
1935	2.83	0.38	13.4
1936	3.23	0.43	15.0
1937*	2.75	0.30	10.9

* Ten months.

Figure 1. Acceleration characteristics



In order to eliminate, in so far as possible, the human element, a skilled and specially trained driver operated the vehicles during all tests. The test busses were equipped with special apparatus to measure performance. Acceleration and deceleration were measured by a Hasler-Tel recording accelerometer, which is essentially an integrating speedometer that records distance traveled in feet, time in seconds, and mean or integrated speed during each second. The meter was driven by means of a bicycle wheel, mounted on the side of the bus. Combustion efficiency was measured before each series of acceleration runs, with an Orsat exhaust gas testing apparatus. An electric tachometer measured engine speed.

Acceleration runs were operated over a 2,100-foot strip of concrete highway that had a slight but constant grade of 0.7 per cent. Runs were operated in each direction, and the average acceleration characteristics for the gas-electric and mechanical-drive busses are shown graphically, figure 1. It is evident from comparison of these speed-time graphs that instantaneous acceleration values for the mechanical-drive bus are slightly higher than corresponding values for the electric-drive bus. This advantage is more than offset by time required for gear changes in the mechanical-drive bus, with the result that road speed of the electric-drive bus is slightly higher over the operating range. For comparative purposes, the speed-time graphs for the two vehicles can be considered essentially identical. It would be concluded from a comparison of acceleration characteristics that there would be a negligible difference in relative scheduled speed ability between the electric-drive and mechanical-drive busses. This conclusion is contrary to normal operating experience, and further analysis is necessary to determine whether other factors affect the scheduled speed ability of the two types of vehicles.

Fuel consumption of the electric-drive and mechanical-drive busses was measured at varying stops per mile, under rigidly controlled operating conditions. Tests were made over a closed course having a measured distance of

one mile. In order to minimize operating variables to the greatest possible extent, all tests were made with maximum engine performance, that is, with wide-open-throttle acceleration and no coasting. Operating speed and time were measured with a Hasler-Tel performance meter. Fuel consumed during each test run was accurately weighed, using a platform scale calibrated to 1/100th of a pound. Temperature and specific gravity of the fuel were also obtained in order to convert weight of fuel consumed into gallons.

Fuel consumption tests were conducted, with a fixed operating cycle of maximum acceleration between stops and a seven-second standing time at each stop, for various stop frequencies between four and eight stops per mile. The mile closed test course had been surveyed and stops were made at fixed points during the test runs. The comparative fuel consumption for electric-drive and mechanical-drive busses is shown in figure 2. Fuel consumption as determined by these tests indicated that use of the electric drive increased fuel consumption 22.9 per cent at four stops per mile and 23.1 per cent at eight stops per mile.

During tests to measure fuel consumption of each type bus, the elapsed time for each run was measured in order that scheduled speed at varying stops per mile could be calculated. The comparative scheduled speed in miles per hour for the electric-drive and mechanical-drive busses is shown in figure 3. It is apparent, despite the fact that the acceleration tests indicated negligible difference between the scheduled speed ability of the two vehicles, that the electric-drive bus constantly maintained a higher scheduled speed than the mechanical-drive bus. Scheduled speed operated by the gas-electric-drive bus was 6.4 per cent faster at four stops per mile, and 8.6 per cent faster at eight stops per mile.

Test data shown graphically, figures 1, 2, and 3, were measured under conditions controlled so as to insure to our satisfaction that measurement of performance characteristics were comparable between the two vehicles and that results could be duplicated between successive runs. We would not defend the accuracy of these measurements from an absolute or scientific viewpoint, but we believe that they may be used as a basis for predicting the relative differences in performance between the gas-electric-drive and mechanical-drive bus.

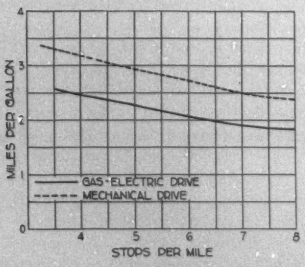


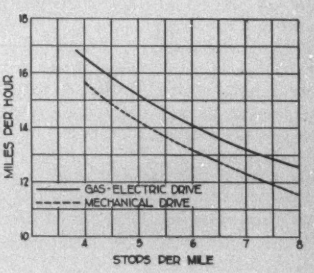
Figure 2. Fuel consumption

Selection of bus equipment is fundamentally a question of economics and in the final analysis the relative advantages of a particular type vehicle can and should be reduced to terms of dollars and cents. Comparison between the electric-drive and mechanical-drive vehicle can be made in terms of dollars and cents, predicated upon the results of the tests conducted, adjusted to take cognizance of operating experience. The problem may be reduced to a simple equation:

Net income per vehicle = total revenue − total expense

Since the only variable under consideration is the drive mechanism, analysis of those factors, inherent in the electric and mechanical drives, and the evaluation of their effect on revenue and expense, will indicate which of the two types of drive mechanism is best suited to the operating requirements. Many of the factors are indeterminate, but a qualitative estimate of their value may be approximated. Evaluation of these factors represents the personal viewpoint of the author, and it is acknowledged that there may be wide divergence of opinion as to the interpretation of the basic information herein presented.

Figure 3. Scheduled speed



Total revenue may be a function of the traffic promotional value or sales appeal of the vehicle. It would seem self-evident that the electrice-drive bus has a greater sales appeal to the public than the mechanical-drive vehicle. The quiet, smooth, and uninterrupted acceleration characteristics resulting from use of the electric drive offer a more attractive ride to the passenger. The operator being relieved from the mechanics of gear-changing operations, is less fatigued at the end of the day's run. Public relations can be improved by use of the electric-drive bus, since driver fatigue is one of the usual causes of frayed nerves, snappy and discourteous retorts, and slovenly operating practices.

One advantage of the electric drive that is seldom considered is the decrease in "gassing" effected by eliminating overdrive of the engine during deceleration. One of the greatest single sources of complaint in bus operation, both from passengers and residents along the bus route, is the obnoxious exhaust gases discharged by the engine. This problem has attained proportions that justify consideration of the decrease in volume and change in characteristics of the exhaust gases discharged by the engine of the gas-electric bus due to its freewheeling action

during declerating periods. Evaluation of these advantages accruing from use of the electric drive is obviously impractical, but its is believed that some weight should be given to the inherent "sales appeal" of the electric drive in any analysis of the advantages of that type vehicle.

Operating expense is an all-inclusive factor that can be subdivided to minute detail. The major components of operating expense that are appreciably affected by the type drive utilized, include depreciation charge per vehicle, platform wages, gasoline or fuel cost, and maintenance expense. These factors can be estimated to some degree on the basis of known performance for each type bus.

Depreciation charges are a function of the difference in initial cost of the two types of vehicles and their probable economic life. Additional cost for the electric drive will vary, but can be assumed to be approximately ten per cent of the cost for a 35- or 40-passenger bus. Since depreciation charges will normally range from 2.5 to 3.5 cents per mile, use of the electric drive will increase the direct operating expense from 0.25 to 0.35 cents per mile, if we assume equal mileage life for the gas-electric and mechanical-drive busses. However, experience of the Philadelphia Rapid Transit Company would indicate that use of the electric drive prolongs the useful life of the vehicle by decreasing rate of obsolescence and decreasing physical deterioration of the vehicle. Evaluation of the potential increase in useful life of the electric-drive bus is a matter of individual opinion and judgment. It may be considered that the actual increase in depreciation charges incurred by use of the electric drive will vary from nothing to a maximum of 0.35 cents per mile, depending upon specific operating conditions and individual judgment.

The claims and counterclaims regarding effect of electric drive on scheduled speed ability of the motor bus, have tended to obscure the facts behind the smoke screen of controversy. The comparative acceleration characteristics of two identical vehicles, one electric drive, the other mechanical drive, were shown graphically, figure 1. These tests would indicate that there is a negligible difference between the probable scheduled speed abilities of the two vehicles. However, actual tests operated to measure scheduled speed ability, shown in figure 3, indicated that there is a definite and appreciable difference in scheduled speed operated by the two busses. The electric-drive bus operated a faster scheduled speed, varying from 6.4 per cent at four stops per mile to 8.6 per cent at eight stops per mile. These conflicting results can be readily correlated by examination of the conditions under which the tests were operated. The electric-drive bus accelerates automatically, the driver merely depressing the accelerator pedal, and no skill or special technique is required to consistently attain maximum performance. The mechanical-drive bus, however, is accelerated successively through three or more gear ranges. Speed at which gear change is made, and rapidity of gear change affect the acceleration rate of the vehicle. During any acceleration test, the driver is under tension, gear change is made at optimum engine speed, with the minimum of time loss and performance attained is the maximum. During scheduled speed tests there is a natural letdown on the part of the driver, despite the fact that there still exists the necessity for changing gears under controlled conditions. It is apparent that in actual service, the mechanical-drive bus can only approach but never attain maximum performance. The gear-changing operation slows up, and engine speeds at which gear changes are made vary widely from the optimum values. The increased scheduled speeds, shown in figure 3, maintained by the electric-drive bus represent the minimum that could be expected in service. It is concluded that in frequent-stop service, the electric-drive bus could maintain a scheduled speed ten per cent faster than could be maintained by a mechanical-drive vehicle of identical design and construction.

Scheduled speed affects those items of operating expense that are proportionate to bus hours and number of busses operated, provided service frequency permits adjustment of schedules to maintain constant the number of bus miles operated. In short-headway heavy-traffic service, such adjustment is usually possible for any appreciable change in scheduled speed. Increased operating speed will, therefore, decrease in direct proportion, drivers' wages, bus depreciation charges, and certain fixed charges. These expenses will normally average not less than 11 cents per mile for heavy-traffic urban service. An increase in scheduled speed of ten per cent would therefore effect a decrease in direct operating expense of 1.1 cents per mile.

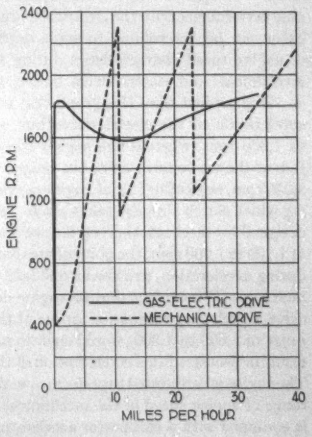


Figure 4. Engine speed during acceleration

Comparative fuel consumption for the electric-drive and mechanical-drive busses is shown graphically, figure 2. These fuel-consumption values were measured at maximum performance, to minimize operating variables, and are not indicative of the values that would be obtained in actual service, although comparison between the two types of busses should be valid. The miles per gallon of gasoline for the mechanical-drive bus were consistently higher than for the electric-drive vehicle, the increase for the mechanical-drive vehicle varying from 22.9 per cent at four stops per mile to 23.1 per cent at eight stops per

mile It will be noted that the percentage increase is practically constant over the range of service conditions from four to eight stops per mile. It may be assumed that determination of comparative fuel consumption under known conditions of actual operation will be a measure of difference in fuel consumption for the two types of vehicle. These busses were operated for a period of two months in actual passenger service. Two groups of runs were selected having similar traffic characteristics, and the drivers assigned to these runs were instructed in operation of the test busses. To eliminate, in so far as possible, variables of operation, the busses were interchanged each week between the two groups of runs. At the end of the two months' period, the mechanical-drive bus averaged 4.27 miles per gallon of gasoline and the gas-electric bus averaged 3.50 miles per gallon of gasoline, an increase of 18.1 per cent in miles per gallon of gasoline for the mechanical-drive vehicle.

Difference in fuel consumption between the mechanical-drive and electric-drive busses was measured with standard design engine and standard engine adjustments. The engine design and adjustments are predicated upon requirements of the mechanical drive, which differ radically in many respects from the requirements of the electric drive. Comparison of the requirements for optimum engine performance with the electric drive and the mechanical drive can be determined to some degree by comparison of engine speed characteristics during acceleration of the mechanical- and electric-drive busses, as shown in figure 4. It is evident from this graph that engine speed during acceleration of the electric-drive bus, ranged from 1,600 to 1,800 rpm, whereas the engine speed during acceleration of the mechanical-drive bus ranged from 1,100 rpm to 2,350 rpm, neglecting initial engine accelerating period during which clutch slippage takes place. Since the engine is designed for mechanical drive, it develops maximum torque at 1,100 to 1,200 rpm, the point of maximum power demand during acceleration, and the torque falls off as engine speed increases. It is evident that an engine designed for electric drive, developing maximum torque at the operating speed range of 1,600 to 1,800, would operate more efficiently and result in decreased fuel consumption of the gas-electric bus. The engine is carbureted to perform over the entire operating range of engine speed of the mechanical-drive vehicle, and is equipped with a carburetor accelerating pump to insure pickup at low engine speed and heavy load. The electric-drive vehicle does not require this type of carburetion, and fuel economy can be attained by adjusting carburetion in the electric-drive bus to actual operating requirements. Test data have also indicated that the permissible maximum engine compression ratio that can be operated without detonation, using a given fuel, is substantially higher with the electric drive than with the mechanical drive, due to relatively constant speed operation and the elimination of low-speed operation at heavy load. It is believed that increased use of the electric drive will tend to focus attention on the inherent possibilities of improved economy to be derived from changes in engine design to meet the actual conditions under which the engine operates with the electric drive. Although the test data would indicate that use of the electric drive results in an increased fuel consumption of from 18 to 20 per cent, equivalent to from 0.5 to 0.8 cents per mile, it is concluded that these estimates represent the maximum probable increases in fuel operating expense. Development of an engine design properly adapted to requirements of the electric drive should decrease the differential in fuel expense to a fraction of the indicated value.

Differences in maintenance expense for the electric-drive and mechanical-drive busses can be approximated qualitatively by analysis of the characteristics of the two types of drive mechanisms. It has been shown, table I, that maintenance expense for electric-drive equipment operated by PRT during recent years has varied from 10 to 13 per cent of total maintenance costs. The electric-drive equipment operated is of obsolete design and it is considered that maintenance cost for modern commutating-field equipment would be substantially less than the costs experienced. It is believed that the expense for the electric equipment should not appreciably exceed expense for clutch and transmission equipment of modern busses with remote engine location. There are a number of characteristics of the electric drive that contribute to lowered maintenance costs. Elimination of the shock of clutch engagement tends to minimize wear on axle gearing and lessen the general wear and tear on the entire vehicle. Engine maintenance is definitely decreased due to relatively constant-speed operation and elimination of high engine speeds, as shown graphically, figure 4. In addition, the ability to measure readily engine performance, by rheostatic loading of the power generator at periodic inspection intervals, contributes materially to improved engine maintenance. Free-wheeling action with electric drive further lessens engine wear and tear by eliminating overdrive of the engine. It may be concluded that there is a definite probability of lessened maintenance expense with the electric drive.

There is one other important factor that should be considered in weighing the relative advantages and disadvantages of the electric drive. Although bus operation is a relatively new industry it will be confronted in the future with the problem of increasing age of its employees and the resultant impairment of the physical abilities of individual drivers.

The trend toward increased acceptance on the part of all industry of a social duty toward its employees necessitates adoption of every device that may prolong the useful working life of the employee. The characteristics of the electric drive, in minimizing required driver skill and in decreasing the physical effort necessary to efficiently control the vehicle, permit satisfactory operation of that type bus by individuals that could not operate comparable mechanical-drive busses under the same service conditions. This factor is of paramount importance to those companies that are faced with the problem of extensive substitution of the motor bus for the street car. Many of the displaced car operators can be trained to operate an electric-drive bus who are not capable of satisfactorily operating the mechanical-drive vehicle. Even this advantage of the electric drive has a dollars and cents

value, since the alternative to continuing the employment of many of these employees is to retire them on a pension that must be paid from operating revenues.

The effect of operating electric-drive or mechanical-drive busses on operating expense may be summarized as in table II.

It has been stated that selection of the electric drive or the mechanical drive bus is fundamentally a question of economics. The problem was reduced to the solution of the following equation:

Net income per vehicle = total revenue − total expense

Attempt has been made to evaluate the differences between the two type vehicles in order that solutions to this equation might be developed. It is concluded that in frequent stop, heavy traffic urban service, the electric-drive bus will produce a higher net income than the mechanical-drive vehicle, since it has been credited with increased sales appeal, resulting in a higher total revenue, and decreased operating expense.

Table II

	Economies in Operating Expenses (Cents per Mile)	
	Electric Drive	Mechanical Drive
Depreciation charges		0.00 to 0.35
Increased scheduled speed	1.10	
Savings in fuel costs		0.50 to 0.80
Savings in maintenance expense	0.25 to 0.50	
Total	1.35 to 1.60	0.50 to 1.15

Modern City Transportation

E. J. McILRAITH

IN MOST cities there are enough automobiles to carry all of the citizens at one time. Yet, there is still a great need for public carriers as a part of city life, and this need increases relatively with increase in size of cities. People pay with great enthusiasm for modern automobiles because they satisfy a desire for new style, more power, greater comfort, and higher speed. Public transportation in its service must recognize these desires.

Life today is streamlined, air-conditioned, finger-tip controlled, and wrapped in striking play of colors and lights. A competing company offers radio harmonizing and another must put in automatic tuning. Then comes "no squint," "no stoop," "no squat." It is an era of dramatic selling.

Not even steel making remains the same. It is alloys we need now. Yet, sales increase because people spend their money for whims, and the whims of yesterday become, through advertising, the needs of today. Trade grows and the keen organization gets its share, while the old shop gets more and more dust and cobwebs.

Transportation has changed, but not fast enough through the last generation. Political control fastened itself upon the street railways and steam railways. Now the other industries have their share of government control, and how they like it. We have grown used to it.

The successive blows of high costs due to the war, automobile competition, the depression, have kept many transportation companies without reasonable earnings for 20 years. Credit has been low, and there has been no sound modernizing plan available to bring back business or build up new lines of trade.

But the long-delayed modernization is now definitely in evidence. The correct solution is not fully understood or established, but experience is molding opinion. A great difficulty is the fact that too many of those who influence transportation are outside of the active management, and seek to find a standard solution applicable everywhere. Even among the operators of transportation systems one finds many expressing fixed opinions as if they were definite and unquestioned axioms.

We hear: Street cars are doomed—two-man car operation is silly—busses are the only solution—small busses are the perfect answer—trolley busses give best service at lowest cost—elevated railways are out.

Some individuals in prominent places believe firmly in the absolute accuracy of one or more of these statements. Each of these statements has definite adherents who are enthusiastically willing to argue for their beliefs, and to spend money based on those beliefs. Actually no one of them is correct in all circumstances, but each of them is true for certain operations, or for certain cities, or for certain circumstances. The great trouble is lack of analysis to determine the different solutions that are needed to give correct answers for the different situations that exist, and to provide the best service with the best operation, and the maximum net return at a reasonable rate of fare. There is no single unit that should be universally used, even in a single city except, perhaps, in cities of very small size.

The transportation industry like any other needs careful thinking and planning, careful analysis and application of sound principles. One doesn't build the same standard factory with an unvarying type of machine tools for a fixed number of workmen to manufacture shoes in one place and containers in another; nor would the same factory be built to manufacture shoes in Chicago as for a factory in Augusta, Georgia. Building a factory or building a transportation system calls for painstaking analysis of the market, the source of supply, the costs of materials, the wage rate, the type of machine tools, the layout of the plant, the operating and working conditions, the trend of public opinion toward the product, the possibilities of molding that opinion, and the probability of producing an adequate net return. Each of these problems has its influence on the success of the whole project.

The final answer that determines the success of an undertaking is the size of the net return after making allowance for the ability to hold the customers by maintaining the quality and price of output. One should not plan for a character of transportation service or kind of unit to be used in giving that service unless it best fits into the production of greater net earnings with satisfaction to the customers. A system should be built around these two objectives, using the best available tools and equipment for each of the many varieties of service within the community served.

Over the years since electric cars have been used, there has been continued progress; better trucks, motors, controls, brakes, doors, bodies, modernized lines but cars were made to last so long that many of the cars you rode on as boys are still with us. Only a pitifully small number of new cars were built each year. That is not real progress.

Ten years ago these facts were recognized and the desire for change finally resulted in the formation of the conference of the presidents of the larger transportation companies and representatives of equipment manufacturers. This conference gave the pressure that comes from large purchasing power to the designing and creation of a truly adequate modern car of two types, for one-man operation and for two-man operation.

Those cars are at last realities operating in several cities and demonstrating definitely that a street car can also be

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thoroughly modernized. The 1937 model car is speedy, sleek, quiet, attractive, and even as modern in appearance as the best bus and much more comfortable to ride. The next models will be better yet.

The new car has excited public interest as an innovation, has attracted many new riders and has gained for the railways new confidence in sound thinking to build a balanced, competent system, using adequate equipment for each transporation need.

What are the transportation needs?

Twenty-five years ago the only public carrier was still thought to be a street car on rails. Then came busses, first as unwieldly, awkard looking, as the early automobiles were, but improving steadily and developing through the years, even as automobiles have developed. Today the modernized bus has reasonable speed, power, comfort and has cleared most of its principal handicaps, except those of heating, lighting, ventilation, fumes of exhaust, and smoothness on uneven pavements.

As bus manufacture became more competent, trolley busses of an efficient type and of adequate performance were developed. Now we have an equally quiet, equally modernized street car for either one-man or two-man operation and surface units run the entire range from private automobiles to small busses to the largest bus, or trolley bus conveniently usable on city streets, into the rail vehicles for lines of heavy density of travel, all running speedily, quietly, smoothly, comfortably.

A full discussion of the relative merits and proper use of these units in a short paper is quite out of the question, but a brief reference to their relative positions is necessary. The principal reason for variety of unit is due to the difference in costs of maintenance, operation, and the various fixed charges to be met.

One cannot depend safely upon general figures on the relative cost per mile of operating street cars, busses or trolley busses, although that is what many managements seek to do, attempting to use approximate estimate as a measuring stick in determining the relative place of each of these types of vehicle. There is no uniform measure that can be correctly used as a generality even for a given city with a single organization and a single scale of wages, working conditions, and costs of material. One must study the cost of each single line and compare the analysis of several types of lines as costs would be for each of these several types of vehicles available to make clear the reason for this statement. The relative importance of operator's wages, milage, costs of maintenance and operation, and fixed charges such as interest on investment, depreciation, insurance, taxes, licenses, and city imposts, vary widely in their effect, dependent upon the characteristics of the operation of the street or line in question.

Unless one has made intimate analysis of proper scheduling of an operation and has found that waste in scheduling is so easily glossed over and ignored, he will not be aware of the significance of intimate study. Very few people understand the possibilities of careful schedule-making, and few schedule departments experience from management intensive understanding, supervision and pressure toward correct analysis and technique.

A few specific illustrations of relative total costs may indicate the need for applying careful, complete analysis to single lines before reaching conclusions as to size of unit or type of operation.

There are three lines in Chicago of nearly the same length but somewhat different riding characteristics. Number 1 carries 53,000 people per day, number 2 60,000, number 3 44,000. Careful detailed analysis of all the factors affecting operation, costs, and investments for each of the various types of operation—two-man cars, one-man cars, trolley busses and gasoline busses—shows that number 1 line would be best served by one-man cars, saving $30,000 per year over the next best type of operation. Number 2 would have the best net return by the use of two-man cars, saving about $25,000 more than by any other method. Number 3 line having somewhat lighter travel and different distribution is best served by trolley busses and these would be best by about $50,000.

By general measures of classification these three lines are alike and directly comparable. It would be easy to create the conviction that the three routes should be treated alike, yet, the net return to the company can be greatly improved by individual decisions and careful application of correct equipment.

The differences are created by the use of the lines by the passengers; that is, the relative intensity of the rush hour as compared to the nonrush period, the relative number in rush hour and nonrush using each of the two directions of travel, the length of ride of the passengers on the line, the zones in which they ride and the number of times the load changes on each trip.

Further, to demonstrate relative costs on one of these lines, index figures for the various types of units are:

Two-man car	118
One-man car	111
40-Passenger gas bus	108
30-Passenger gas bus	114
40-Passenger trolley bus	104

An even more striking illustration can be given by comparing two routes of exactly the same length. One, now a trolley bus line, carries about 19,000,000 passengers per year; the other is a one-man car line carrying 17,000,000 passengers. The average load per car or bus in rush hours in the rush direction is almost exactly the same for the two lines but because of the variations in such factors previously mentioned the total operators' hours paid for on the trolley bus line is 56 per cent higher than on the one-man car line.

Further analysis of the costs of giving gasoline bus service with different sizes of gasoline busses indicates again that general conclusions are likely to result in errors. One line using seven 30-seat busses could be operated with ten 20-seat busses of the same quality and general appearance, except for size, at a saving of around $7,000 per year, and with a reduced investment in busses from $63,000 for the 30-seat bus to $45,000 for the 20-seat bus. A saving of $7,000 with a reduction of nearly 30 per cent in investment is a very substantial accomplishment on so small a line, but the ordinary operating man would be likely to suggest a 30-seat bus if he looked at the line's operation somewhat su-

perficially or without the careful analysis of the complete details of costs.

On another line using at present ten 30-passenger busses the total cost would be $4,000 more per year if smaller busses were substituted, but the investment would be lower for the 20-passenger bus. In each of these cases one is balancing operators' wages, which are naturally higher with the smaller bus, against costs of operation, maintenance and fixed charges, which are likely to be lower on many of the light lines for the smaller bus.

In most any system of transportation prevailing today in cities there are certain lines built many years ago when only street cars appeared to be serviceable for city service, and which have continued to operate with street cars where a substitution could readily be made at a saving by using trolley busses or gasoline busses as the circumstances would indicate. These two newer types of vehicles are better adapted to certain kinds of operation with lighter densities of travel, and should be a part of a modernized system for those lines on which they are appropriate. No one kind of equipment is adequate for best results in all types of service, and the production of net revenue. Rule-of-thumb methods of deciding upon the type of equipment can bring wrong answers.

Of course, another source of error comes from the use of old figures of costs of operation. New methods of maintenance and newer, better equipment are constantly being introduced in gasoline driven busses of all sizes, in trolley busses, and in street cars. The relative comparisons are an ever changing relation and, just as in all business ventures, transportation management needs to be alert in analysis, study, and in modernization.

The new street car generally known as the PCC, or Presidents' Conference Committee Design, has now been in use for more than a year in a number of cities. In most cities it is used as a one-man car; in Chicago only as a two-man car. But the Chicago car is larger in size with different arrangements of doors to make it adaptable for the carrying of larger loads. This car has distinct accomplishments that make it a completely different street car than has been available. The rate of acceleration is not greater than that of some of the best cars previously used, but is very much smoother and more uniform. Jerks are possible only when the motorman must throw off his control while the car is still accelerating at a rather high rate and must immediately put on his brake to avoid an accident. It is, of course, impossible to make such emergency stops without disturbing standing passengers. This is true in any type of vehicle equipped with efficient brakes.

The brake on the new car is a great improvement because braking is not dependent upon wheel adhesion. The combination of dynamic braking with air braking and a battery-operated track brake permits a quicker stop than is possible with an automobile, not withstanding the condition of the rail. Of course, the rate of braking ought to be selected as one that the passengers can tolerate when standing and holding to a support. But since the motorman knows that he is no longer dependent solely on rail adhesion, he may run closer to traffic, and at much higher speeds so that he may hold his place in the street.

The only way in which greater speed can be developed for a vehicle of this sort is by giving the operator complete assurance that he has a thoroughly dependable braking system that will operate at least as rapidly as that of any other vehicles on the street. The success of gaining speed in operation of these cars, then, has been made possible not primarily because of change in accelerating rates, but also because of improved braking.

The new car also has a much better heating and ventilating system, and uses the heat generated in accelerating and in decelerating by dynamic braking for heating the car. This practically eliminates the use of any other electrical heating, and so cuts the cost materially.

The modernized design of equipment in unit assembly has greatly reduced problems of maintenance and has cut costs in both maintenance and manufacture. The weight of the whole car has been materially reduced by better design, and modernized methods of manufacture, made possible by many companies purchasing from similar specifications, has reduced greatly the manufacturing cost and, therefore, the purchasing price.

However, the outstanding accomplishment is the reduction of noise to a level in keeping with that for busses or automobiles. Without noise reduction the new street cars would be quite incomplete, in spite of the important advantages they have for many lines in all large cities. With the present demonstration of a very quiet street car which can, no doubt, be even further improved in later models, the greatest handicap or source of annoyance has been definitely eliminated.

In the Chicago cars, hand control of the motor circuits and of the brakes is used. The motorman operates the controller with his left hand by a lever that moves vertically through an angle of 22 degrees, the position determining the rate of automatic acceleration chosen. With the right hand he operates the brakes with another lever, also in a vertical plan through an angle of approximately 60 degrees. Here the position determines the automatic rate of deceleration.

This is not quite all the story of the braking controller, because the three forms of braking are not ordinarily all effective at the same time, and the track brakes do not begin to function unless the control handle is moved beyond the middle of its stroke.

The point I wish to make is that we have kept hand control of the movement of the vehicle, while all other properties have gone wholly to foot control in both starting and stopping the car. The principal reason for retaining hand control is that in the operation of a street car no steering is required, so that while the car is running the operator on a two-man car has nothing whatever that he needs to do with his hands, if acceleration and braking are put on foot pedals. Now it isn't good psychology to leave a man at an important job that calls for a high degree of concentration on the smoothness and safety of his operation with his hands idle. One's thinking is too much tied up with what the hands are doing. Hands will not stay idle, and if the operator when operating a car begins to do other things with his hands that take away his attention from safety and smoothness of the car, then the job is being poorly done.

Hand operation with proper kinds of movements can be much more accurate than can foot operation, and due to the flexibility of one's hands, wrists, arms, and body one may make levers move accurately up and down in a vertical direction even though the body is not in a fixed position in a seat.

Other problems remain yet to be settled. All of the new cars in use are front-entrance, center-exit cars. In Chicago a rear exit was also added. But the passengers still tend to concentrate in the front half of the car. It is quite likely that this is inescapable and that in two-man operation it is necessary to have rear-entrance, center-exit, and front-exit, in order that the passengers may be permitted to move in the direction that is psychologically sound, and in which they are most easily trained, instead of trying to force the passengers to go back to alight at points farthest from the crosswalk. The street intersection seems to be their main objective. While passengers are waiting for a car they will move back toward a boarding point where the rear end will be because they are not wasting time in so doing. When they get off they wish to be at the nearest possible point to the street intersection. It seems that this is too strong a tendency to overcome, and that reversal of the present movement for two-man cars will not only accomplish better distribution of the loads, but will also tend to reduce accidents within the car, because the passenger will be facing in a better direction for bracing himself against acceleration or deceleration, and in one to which he has been accustomed over a long period of years of training.

However, the car has been a notable success, and undoubtedly large numbers will be built and used in many cities in modernization now underway. It seems quite important that electrical operation be retained in cities. Certainly the air in the streets is cleaner and better without the annoying fumes of gasoline driven units. Fortunately, on heavier lines electrical vehicles, either street cars or trolley busses, are more economical and perhaps it is much better to have transportation systems largely dependent on central station energy than to be dependent on gasoline or oil, which may become in a few years relatively more difficult to obtain and more costly in use. The source of gasoline is not unlimited. Of course, if Diesel engines can ultimately be developed to be utilized to advantage, the increased use of Diesel oil will also cause a rise in price, but Diesel engines in city service need to be equipped as Diesel-electric type, which produces added complications.

But electrically controlled vehicles served by central stations would have marked advantages from the standpoint of fumes, better heating, lighting and ventilation, lessened noise, greater dependability in power source, and they may also be made larger. Street cars and trolley busses are permitted to be wider than gasoline driven busses because they cannot get away from their city streets into state highways, and when wider may have wider aisles, wider seats, wider doors, and generally better transportation convenience for lines of frequent interchange of passengers.

The conclusion that should be reached from this discussion is that a process of change is going on. Modernization and improvement is vitally necessary, but accurate thinking indicates the need for care in making decisions. Sound transportation planning will utilize all the best ideas and will develop plans that will permit continuing modernization.

Thyratron Reactor Lighting Control

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Synopsis: The introduction of electron tubes and power saturable reactors for the control of theater and mobile lighting has made possible the design and construction of lighting control equipment of greater efficiency and flexibility than was possible with the older methods of control. This paper describes some of the new equipment, systems, and practices.

Several control systems for the pilot controller, the individual, and master units are described and illustrated. The basis for the intensity scale for the control units in the pilot controller is given.

Introduction

IN A PREVIOUS paper,[1] an electron-tube saturable-reactor circuit was described which has proved to be a basic element in the development of a system of theater-lighting control adaptable to a wide range of applications. In applying this circuit it has been possible not only to enlarge former systems of control, but also to develop new and more flexible systems which have proved to be of great practical value. It is the object of this paper to explain some of these systems and the characteristics of some of the component parts.

The theater-lighting control equipment here described is made up of two basic parts, reactor groups and a pilot controller. The reactor groups consist of thyratron-tube panels, distribution panels, saturable reactors, and booster transformers, which regulate the amount of power supplied to the lamp circuits. These reactor groups can be located in any remote place, but are usually situated at a load center. The pilot controller is constructed in the form of a console or vertical panel from which the operator has control of all lighting circuits and is located in front of or at the side of the stage in order that the operator may see the lighting effects which are being produced.

Control Units

The pilot controller consists of individual intensity-control units, master intensity-control units, etc. The number of each used and their arrangement depends upon the control system employed and the number of lighting circuits. In each of these units there is a small lever or knob moving on a calibrated scale for controlling the light circuit intensity.

An outstanding advantage of the thyratron-reactor control over resistance dimmers is the fact that the calibration of this intensity scale serves two purposes:

1. It acts as an index or guide for resetting the lighting circuit and
2. It is a true indication of the percentage of light intensity.

This latter condition is based on an experimental determination[2] of a series of reflecting surfaces which represent a series of equal differences in brightness sensation for the average observer. The intensity scales are arbitrarily marked from zero to ten and correspond to equal divisions of brightness sensation, i.e., zero on the intensity scale indicates no light, five indicates 50 per cent brightness, and ten indicates 100 per cent brightness or maximum light output. Plotting light output in per cent lumens against the intensity scale gives the ideal curve (figure 1, curve *A*). Converting per cent lumens to volts for Mazda *C* lamps[3] provides a convenient basis of comparison for determining how closely control units give results approaching the ideal curve (figure 1, curve *B*).

By referring to illumination levels on a percentage basis, a new terminology is made available to the lighting director since the calibration of the intensity scales is in

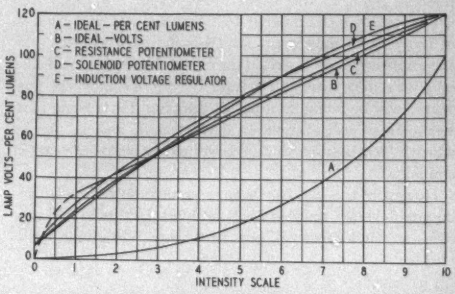

Figure 1. Ideal and actual characteristic curves of individual control units

A—Ideal, per cent lumens
B—Ideal, volts
C—Resistance potentiometer
D—Solenoid potentiometer
E—Induction voltage regulator

units which are proportional to the brightness sensation of the human eye.

Individual Intensity-Control Units

1. Resistance Potentiometer. A resistance potentiometer was used as the intensity control unit in the description of the theater lighting control circuit previously referred to. The current drawn by this circuit from the intensity control unit is about three milliamperes and hence a resistance potentiometer of small physical size and having a resistance of several thousand ohms can be

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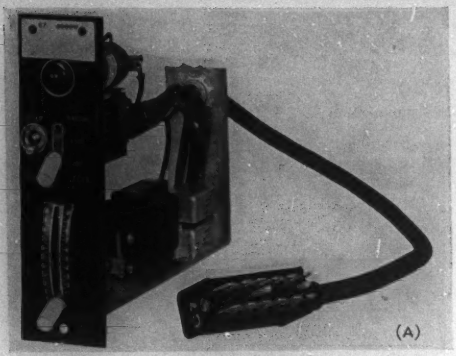
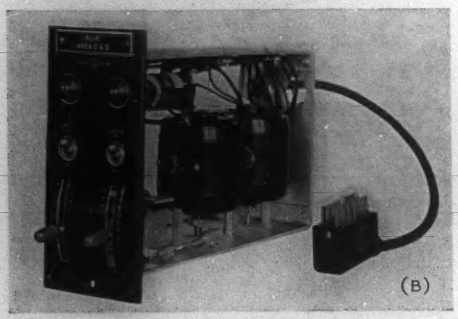
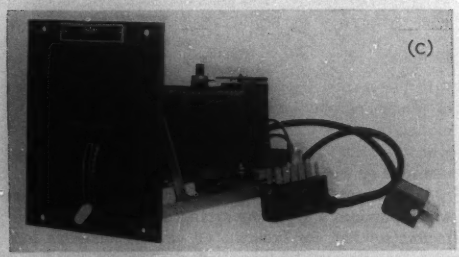
1. For all numbered references, see list at end of paper.



A—Solenoid potentiometer type



B—Induction voltage regulator type



C—Master (above) *D*—Scene fader (below)

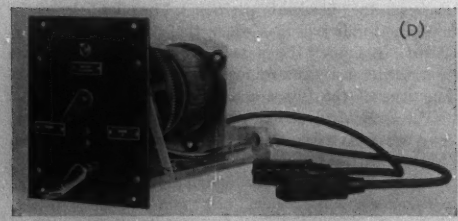


Figure 2. Control units

used. The potentiometer is usually mounted with the shaft perpendicular to the face of the unit so that the control knob is turned to control the lamp circuit intensity. Uniform wire-wound potentiometers are usually used, and the intensity scale calibrated to correspond as nearly as possible to the ideal characteristic (figure 1, curve *C*).

2. Solenoid Potentiometer.[4] Figure 2*A* illustrates a typical control unit using a solenoid potentiometer. Control of the lamp intensity is effected as follows:

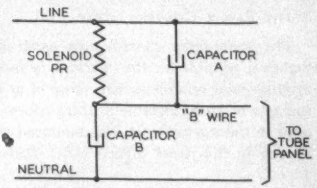


Figure 3. Connections of solenoid potentiometer

Referring to figure 3, change of voltage between the *B* wire and neutral is obtained through the resonant rise and fall of voltage across capacitor *B* as the inductance of solenoid *PR* is varied from a low to a high value. That is, solenoid *PR* goes from series resonance with capacitor *B* into parallel resonance with capacitor *A* as the inductance of *PR* is increased. From the above description, it is evident that this intensity control consists of a regulating scheme similar to an ordinary resistance potentiometer but employing solenoid *PR*, capacitor *A*, and series capacitor *B* to control the voltage magnitude existing between the *B* wire and the neutral through the variation of the inductance of *PR* caused by the change in position of an iron core rather than by the change in position of a sliding contact. The intensity scale is uniform because the proper selection of solenoid coil and capacitors gives an intensity calibration (figure 1, curve *D*) which closely approaches the ideal characteristic.

3. Induction Voltage Regulator. A control unit using induction voltage regulators is shown in figure 2*B*.

The induction voltage regulator consists of a stator winding and a rotor winding. The stator winding, when connected to an a-c source, induces a voltage in the rotor winding depending upon the relative positions of the stator and rotor. In order to use an induction voltage regulator as an individual intensity control unit, it must be of small size. However, it has been impractical to build a regulator whose maximum rotor voltage is as high as that required by the tube unit. Therefore, to increase this voltage a transformer is connected between the rotor and the tube unit. The induction voltage regulator generally is not used singly, but in conjunction with similar regulators in preset control systems. As the curve of output voltage versus angular position of the rotor is sinusoidal, a uniform intensity scale can be used because the proper selection of mechanical linkage gives an intensity calibration (figure 1, curve *E*) which closely approximates the ideal characteristic.

Master Intensity-Control Unit

The master intensity-control unit is used to control a group of individual units or other master units. It usually consists of a toroidally wound adjustable autotransformer so arranged that power may be tapped from any turn of the winding. Any voltage from zero to full value may be obtained from this device with but small increments of voltage between steps. One form of a master in which the adjustable auto transformer is operated by a rack and pinion is shown in figure 2*C*.

Scene-Fader Control Unit

The scene-fader control unit used in preset systems makes it possible for the operator to fade the light circuit intensities of one scene into those of another. It usually consists of an adjustable autotransformer similar to that used in the master unit, but mounted with shaft perpendicular to the panel (figure 2*D*). Instead of the lever a small crank is used through reducing gears to slowly adjust the transformer.

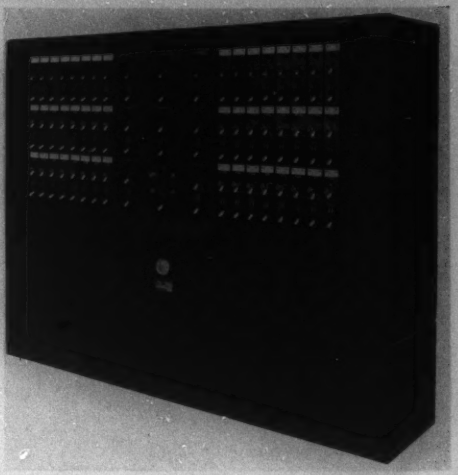


Figure 5. Pilot controller using rehearsal system

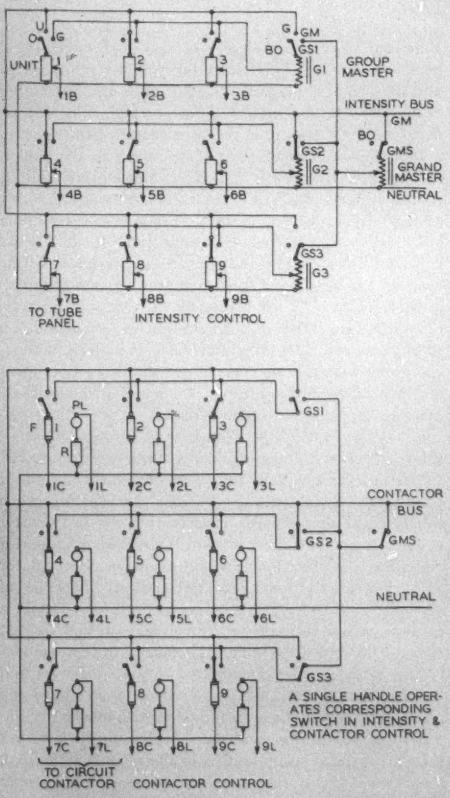


Figure 4. Schematic of pilot controller—typical rehearsal system

Systems

As pointed out above, the pilot controllers consist of individual units, master units, switches, etc. In general, the systems of control for the pilot controllers are classified as rehearsal, preset, rehearsal and preset, or modifications of these.

Rehearsal System

In the rehearsal system, individual units are arranged in groups and may be controlled from a group (or color) master, and these masters may in turn be controlled from a grand master. Figure 4 shows, schematically, a typical rehearsal system.

A contactor control may be included in the system, which provides a switching arrangement for circuit contactors so that, for example, all circuits connected to a group master may be turned off quickly and simultaneously by putting the three-position switch in the group master in the "blackout" position. The pilot light on the individual unit indicates when the circuit contactor is closed. In figure 4 the contactor control is shown separate from the intensity control for clarity, whereas actually the functions of the two are combined.

The individual units, illustrated as potentiometers, may be connected to the "off," "intensity line bus," or a "group master intensity bus" by their three position switches. The customary designations for these three positions are "off," "unit," and "group master," respectively. In figure 4, circuit 6 is in the "off" position, circuit 4 is in the "unit" position, and circuit 5 is in the

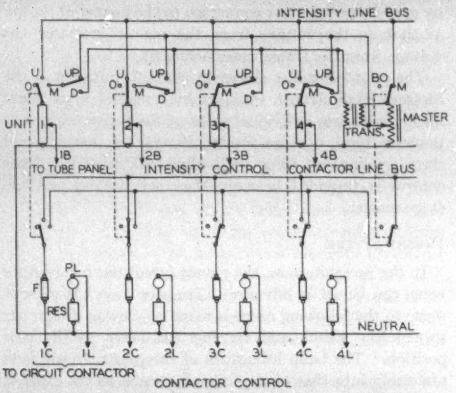


Figure 6. Schematic of pilot controller—rehearsal system with cross control between individual units and master unit

Figure 7. Pilot controller—Rehearsal system with cross control between color masters and stage master

"group master" position. As the lamp intensity of each circuit depends upon the voltage between the *B* wire and neutral *N* for the respective circuits, the lamp intensity for circuit 6 will be zero, for circuit 4 will depend upon the setting for that individual unit, and for circuit 5 will be proportional to the setting of that individual unit and group master 2. For example, if the individual unit and the group master are each set at one-half intensity position, the lamp intensity will be one-fourth. If units 4, 5, and 6 are connected to the group master and one is set at full intensity position, another at one-half, and the third at one-fourth, then as the master unit is increased from zero to full, the intensity of each circuit will increase in proportion, reaching full, one-half, and one-fourth, respectively, when the master reaches the full intensity position.

The group masters are connected to the grand master when their three-position switches are in the "master" position, to the line when the switches are in the "group" position, or off when the switches are in the "blackout" position. The lamp intensity of a lighting circuit, whose control unit is connected to the group master and the

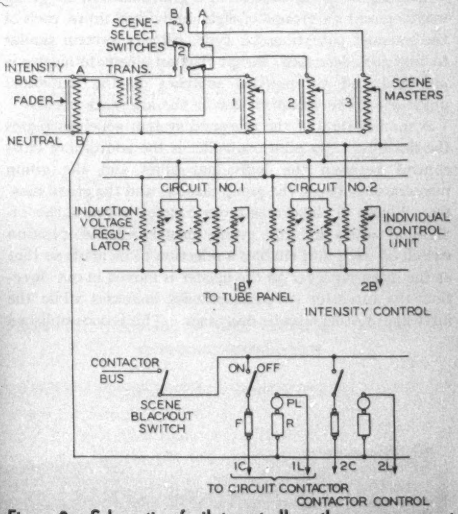


Figure 8. Schematic of pilot controller—three-scene preset system

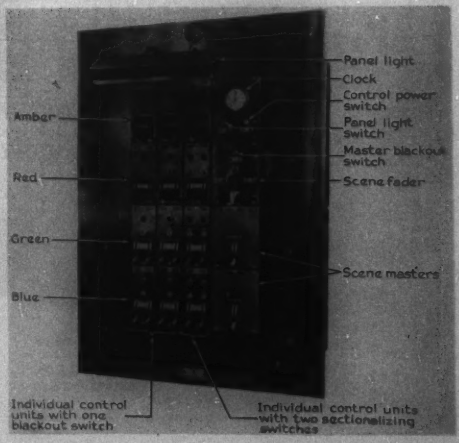


Figure 9. Pilot controller using two-scene preset system

group master connected to the grand master, will be proportional to the setting of the individual unit, the group master, and the grand master. For example, if the unit, group master, and the grand master each are set at half intensity, the lamp intensity of the lighting circuit will be $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$. Units which are connected through the group masters to the grand master can be turned off by putting the two-position switch on the grand master in the "blackout" position.

The pilot controller shown in figure 5, installed at the University of Iowa, consists of a grand master, six group masters, and six groups of eight individual units, each of the solenoid potentiometer type, using a system similar to that just described, except that an alternate master is provided and two-position switches on the individual units select the group master or the alternate master.

A modification of the rehearsal system which increases the flexibility of a pilot controller is the addition of cross control between the individual units and the group masters, or between the group masters and the grand master. Figure 6 illustrates cross control between the individual units and the group master. A two-position switch on each unit enables a selection to be made so that as the intensity lever on the master is moved in one direction the intensity of some circuits increases while the intensity of other circuits decreases. This is accomplished by use of a transformer connected to the master as shown, so that as the voltage from the master increases the voltage from the transformer decreases.

The pilot controller shown in figure 7, installed at the Stetson High School, Philadelphia, consists of a house master with two individual units of the resistance potentiometer type, a stage master, three color masters, and three groups of three individual units each. Cross control is provided between the color masters and the stage master.

Preset System

In the preset system, the circuit intensities for a future scene can be set in advance. Transfer from the present scene to the following scene is made by closing the proper scene-select switch and turning the fader to the new position. The lamp intensities of the present scene fade uniformly into that of the following scene as the fader is turned. In this transfer the primaries of the voltage regulators[5] of the present scene are de-energized while the voltage regulators of the future scene are energized. The voltage from the secondary of the regulators depends upon the primary voltage and the angular position of the rotor with respect to the stator. For example, in figure 8 suppose circuit 1 is set at one-half intensity in the present scene (scene 1) and is to be full intensity in the next

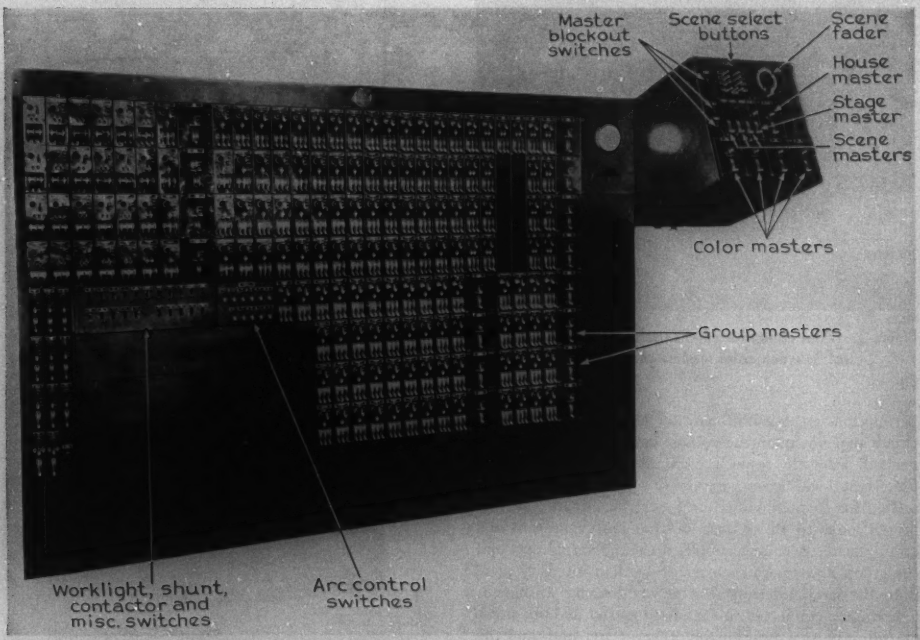


Figure 10. Pilot controller using rehearsal and three-scene preset system

scene (scene 2), and circuit 2 is at full intensity and is to be zero intensity in the next scene. The scene-select switches and fader are as shown, and it is seen that the primaries of the scene-1 regulators are energized and the other regulators are not energized. The scene-2 regulator for circuit 1 is placed in the full intensity position and the scene-2 regulator for circuit 2 is at the zero position. Then by turning the fader from *A* to *B* the voltage decreases on the primaries of the scene-1 regulators from maximum to zero, and at the same time increases the voltages on the primaries of the scene-2 regulators from zero to maximum. The lamp circuit intensity for circuit 1 has thus increased uniformly from one-half to full, and for circuit 2 has decreased from full to zero. All units of a given scene can be controlled by the scene master. For example, the scene-2 master can now be used to dim all units on scene 2.

The scene-select switches in figure 8 are not required if a preset system for only two scenes is used. In this case each individual unit has but two voltage regulators for intensity control. The scene-1 regulator stators are energized and the scene-2 regulators de-energized when the fader is turned to the scene-1 position. On turning the fader to the scene-2 position, scene-1 regulators are de-energized and scene-2 regulators are energized. Figure 9 shows the pilot controller installed at Maple Leaf Gardens, Toronto, Ont., Canada, which is of this two-scene preset type.

Preset and Rehearsal System

An extremely flexible control system is made by combining the rehearsal system and the preset system. Such a combination provides a single pilot controller having the advantages of both systems. A three-scene preset and rehearsal control system is used in the pilot controller (figure 10) for the stage lighting circuits at the Metropolitan Opera House. The scene fader, scene-select switches, scene masters, stage masters, and group masters are the same as in the previously described systems. Refer to figure 11. The individual control unit consists of three induction voltage regulators and a three-position switch. Each of the three positions of the switch represents three different connections of the individual control unit: (1) "unit," wherein the circuit intensity is controlled only from voltage regulator number 1; (2) "group," wherein the circuit intensity is controlled from voltage regulator number 1, the group master, or the stage master, as in a regular rehearsal system; and (3) "preset," wherein voltage regulators number 1, number 2, and number 3 are the intensity controls for scenes 1, 2, and 3, respectively.

Summary

Three types of individual intensity control units, a master intensity control unit, and a scene fader for use in theater-lighting pilot controllers have been described. A scientific basis for a rational marking of the intensity scales on the individual units has been given. Three basic systems of connections for pilot controllers and several modifications of these systems have been described. From the foregoing description of the various systems it may be seen that pilot controllers may be adapted to varying requirements for theater lighting control and furnish a wide variety of possibilities in the selection and production of lighting effects.

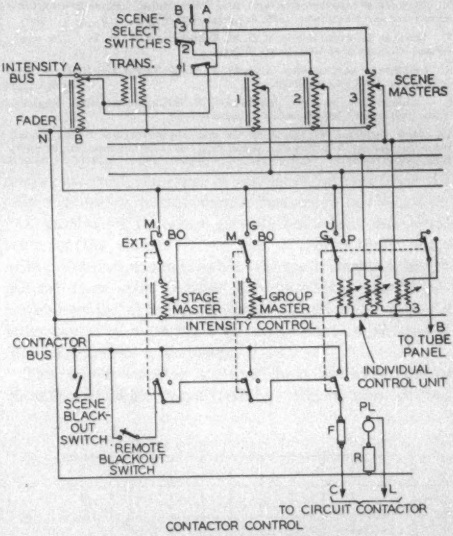


Figure 11. Schematic of pilot controller—rehearsal and three-scene preset system

Nomenclature—Schematic Diagrams

EXT—Extended control from remote blackout switch
F —Fuse in contactor coil circuit
GMS—Grand master switch
GS1 —Switch on group master number 1
PL —Pilot light
R —Resistor

Control-Unit Switch Positions

BO —Black out
D —Down
G —Group master
GM —Grand master
M —Master
O —Off
P —Preset
U —Unit

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Thyratron Control of D-C Motors

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Synopsis: This paper describes the characteristics of new thyratron circuits which have been developed for the control of direct current motors. By means of these circuits it is possible to hold constant motor speed, constant armature voltage, or constant relative speed between two systems. It is also possible to hold constant either an alternating or direct current voltage which is dependent on the speed or position of the armature of a direct current motor.

Introduction

THE USE OF electron tubes in the industrial field has grown steadily for the last ten years. They have found their greatest application where other methods of control could not readily be used or were decidedly inferior. Speed control of d-c motors by means of thyratrons is in direct competition with those using rheostats, vibrating contacts, and other similar forms of field control. The thyratron has the advantage of high efficiency, full control, and quickness of response. The small control energy required, and the quickness of response greatly simplifies the design of precision control circuits and reduces the problem of hunting. A further advantage, in comparison to the rheostat control, is that it is not necessary to make step-by-step calculations of resistor values to obtain uniform control throughout the entire speed range. In general, the power component of thyratron control circuits is limited only by the maximum current to be controlled, and the range of control required. The first determines the size of tubes and power transformers and the second determines the magnitude of the anode voltage. In most applications, since 230 volt motors are used, the range of control is the same, and the only variable is the maximum current to be controlled.

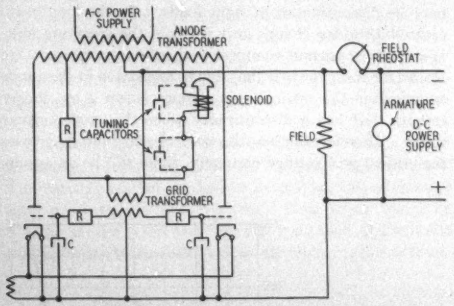

Figure 1. Thyratron field-control circuit with solenoid control

A number of thyratron circuits have been developed both for the control of a-c and of d-c motors. Some utilize feed-back systems to hold the speed constant, but in general, their main function is to provide a smooth adjustable control of the motor speed. There are, however, a large number of d-c motor applications where some type of feed-back system is necessary.

This paper describes some of these feed-back control circuits and their characteristics. Where new circuits were developed every effort has been made toward simplicity and to the use of the same fundamental elements. These circuits can be divided into mechanical feed-back and electrical feed-back systems. In mechanical feed-back systems such as wire reeling applications where the tension of the wire is held constant, the position of a solenoid is varied mechanically, such that the speed of the controlled motor will vary as the reel diameter changes. In electrical-feed-back systems a voltage or current is used as a reference to maintain constant tension or speed or to hold the speed of the controlled motor at some definite relationship with reference to the speed of another motor or system.

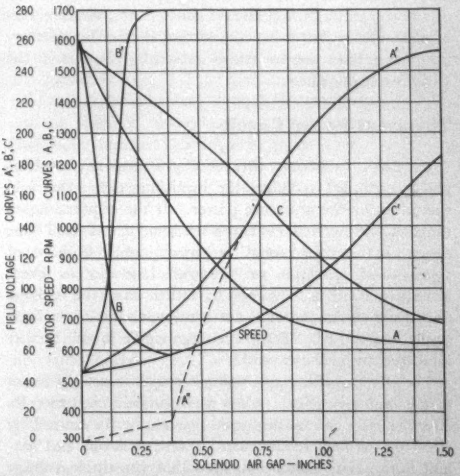

Figure 2. Motor-speed and field-voltage curves for figure 1

Data for this paper were taken on a shunt motor rated

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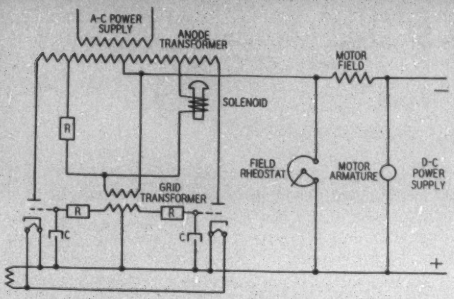

Figure 3. Thyratron field reducing control circuit with solenoid control

one and one-half horsepower, 230 volts, 500/1,500 rpm. In discussing the characteristics of these circuits it has been assumed that these data are typical for the control of any d-c motor. Actually, of course, the characteristics of motors vary, but it is believed that their differences are no greater than the variations caused by changes in the various circuit values.

Thyratron Power Circuit

In these feed-back circuits thyratrons are used as phase-controlled rectifiers for furnishing either the field excitation or the armature power. If the required speed range is narrow, field control is used and if wide or if time delay of the field circuit is objectionable, because of slowness of operation or increased tendency to hunt, armature control is used. In either case the voltage impressed on the motor is not continuous but has a large ripple component. The percentage ripple is still further increased by phase control.

The effect of this ripple voltage is to increase the losses in the motor circuits. When used for field excitation its effect usually can be neglected because of the smoothing effect of the field inductance. A test on a one and one half horsepower motor indicated that the ripple voltage increased the field heating by less than two degrees centigrade.

When used for armature control this smoothing effect is not present and in addition current cannot flow from the thyratrons into the armature circuit until the impressed sinusoidal voltage becomes greater than the counter electromotive force. For this reason unless a smooth ng reactor is used the armature current may consist of a series of impulses which may increase sparking of the commutator and cause an abnormal temperature rise in the commutator and particularly in the interpole windings. In some cases for small motors of one horsepower and less, when a biphase rectifier was used, it has been found more economical to use a larger motor rather than to add a smoothing reactor. Tests indicate that for the same load the motor should be approximately 25 to 35 per cent larger than that required if the ripple voltage was not present. The increased heating in the motor depends upon the percentage of ripple current, which in turn depends upon the reactance in the armature circuit, the number of phases in the rectifier circuit and the ripple voltage produced by phase control. The increased rise in temperature is illustrated by table I.

It will be noted that the greatest rise in temperature occurred in the interpole windings and was caused by increased core and copper losses. The field poles normally

Table I. Temperature Rise in Degrees Centigrade, 1½-Horsepower 230-Volt 500/1,500-Rpm Motor

	With Direct Current Applied. 100 Per Cent Rated Armature Current	With Smoothing Reactor. 100 Per Cent Rated Armature Current (Average Amperes)	Without Smoothing Reactor. 75 Per Cent Rated Armature Current (Average Amperes)
Field windings	50	52.5	48
Interpole windings	40	42	38
Commutator	31	31.5	18

All readings were taken by thermometer immediately after the motor was stopped at end of test. Biphase type rectifier used for thyratron power circuit.

are not designed for the alternating flux produced by this ripple current.

Even with a smoothing reactor the armature current may be discontinuous at light loads. As the load is increased a sudden change may occur in the armature voltage when the current changes to a continuous value. One reason for this change is that due to regulation in the anode transformer the critical grid voltage curve is no longer smooth, but has a discontinuity when the anode current stops. Therefore, unless the control-grid voltage crosses the critical grid voltage vertically, there will be an appar-

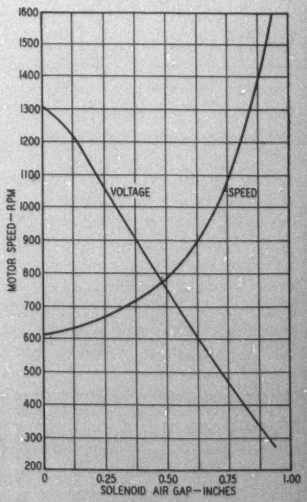

Figure 4. Motor-speed and field-voltage curves for figure 3

ent phase shift in the grid voltage which tends to suddenly increase the output voltage. By using a large inductance this discontinuity can be made to occur at such a low value of current that the control is not affected. Where it is impractical to use a large reactor there are two other methods which can be used to reduce the effect of this discontinuity to a negligible value. A resistor can be connected across the reactor or a phanotron tube can be connected across the output terminals of the rectifier circuit. In the first case the transition point is raised above the maximum load current value, without seriously increasing the heating in the motor, and in the second case the phanotron, because of its low effective resistance, increases the time constant to such a value that the discontinuity occurs at a very small value of current and has the effect of using a reactor of greater size.

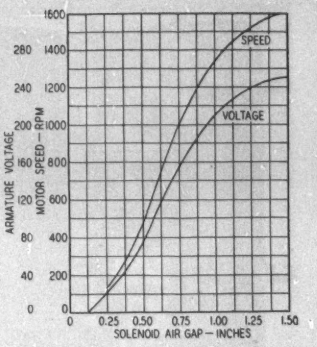

Figure 6. Motor-speed and armature-voltage curves for figure 5

Control Circuit

Numerous methods have been developed for varying the apparent phase of the thyratron grid voltage. One method is to superimpose a variable d-c voltage on a fixed a-c voltage; another is to vary the phase of a peaked voltage, but the simplest method is to use a sinusoidal voltage of adjustable on variable phase. The superimposed control has the disadvantage, unless an amplifying tube is used, that the control voltage is so low that the variation in thyratron characteristics, caused either by changes in temperature or by usage, tends to limit their application or to have them discarded before their ultimate life was reached. With variable phase control the grid voltage can be made large enough to compensate for these variations.

A common method of obtaining phase control is to use a variable reactor in a resistance-reactance bridge circuit. The variable-reactor method of control has the advantage that contacts are not required. If a small saturable reactor is used for the variable-reactance element its reactance can be smoothly varied by changing the saturating current. For mechanical feed-back systems the ordinary solenoid is satisfactory for the variable-reactance element.

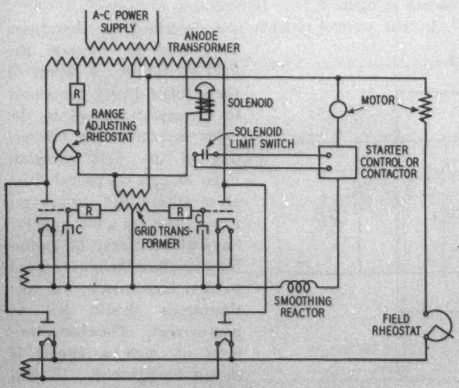

Figure 5. Thyratron armature-control circuit with solenoid control

If the reactance is varied from zero to infinity, the voltage from the midpoint of the bridge power supply to the junction of the resistor and the reactor will vary from the in-phase position to 180 degrees lagging with reference to the applied voltage. If the thyratrons supply a resistance load this range of control is required. In d-c motor applications there is always some reactance present which materially reduces this required phase angle shift. In addition, it is possible to still further reduce the required reactance change by partially tuning the reactor with capacitors.

While the data for this paper were taken on a one and one-half horsepower motor, these feed-back control circuits are not limited to motors of this size but can be applied to motors of any size, provided thyratrons of sufficient size are available. At the present time large thyratrons of 100 amperes rating require an appreciable amount of grid power. For this reason the elements in the control circuit must have an appreciably higher rating. The elements as described can be used to control the field excitation of motors up to approximately 100 horsepower and the armature power of motors up to three horsepower. Still larger motors can be controlled either by using small auxiliary thyratrons, or by controlling the field excitation of the generator in a Ward Leonard system.

Antihunting Circuit

In any feed-back system hunting may be caused by time delay in either the control or controlled circuit. It is more apt to occur as the difference in speed from no load to full load is decreased. A common method of eliminating hunting is to slow the response of the control circuit sufficiently to allow the circuit being controlled to respond to the new condition. Slow-speed feed-back systems are inherently stable, but in high-speed systems it may be necessary to either decrease the rate of response or to provide an antihunting circuit.

In electrical feed-back systems one method of eliminating hunting is to feed back into the control circuit a

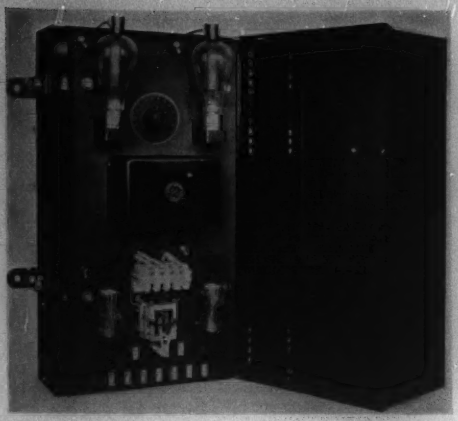

Figure 7. Thyratron control panel for one horsepower d-c motor showing two thyratrons for armature control and two phanotrons for field excitation

voltage which is proportional to the rate of change of one of the circuit voltages. This can be accomplished by impressing one of the circuit voltages on a resistor-capacitor circuit in which the voltage drop in the resistor varies as a function of the rate of change of the applied voltage. This particular method has been found satisfactory in electronic voltage regulators and to be equally as effective in the electrical feed-back systems described below.

Mechanical Feed-Back—Solenoid Control

The circuit of the simple mechanical feed-back system is shown in figure 1. In this circuit the excitation as furnished by the thyratrons is in the same direction as that obtained from the d-c power supply. Should a thyratron fail, the maximum speed of the motor is limited to that value as determined by the setting of the field rheostat and in normal application is approximately ten per cent above the normal maximum speed. The use of this separate source of excitation has still another advantage in that the discontinuity in the field current as mentioned previously is eliminated.

Referring to figure 2, curves A, B, and C show the variation in speed for different settings of the solenoid, and curves A^1, B^1, and C^1 show the variation in the thyratron output or field voltage. By partially tuning the solenoid coil with capacitors, as shown by the dotted lines in figure 1, it is possible to obtain the same degree of control with a smaller variation in the movement of the solenoid core. The untuned characteristics are shown in curves A and A^1 and the limiting tuned characteristics are shown in curves B and B^1. The dotted curve A^{11} shows the effect of the separate field excitation in removing the discontinuity in the field voltage curve. Curves C and C^1 show how these characteristics may be modified still further by changing the value of the fixed resistor in the phase shifting circuit. While these characteristic curves are not linear, their departure usually will not cause any difficulties. In the few cases where a linear relationship is required a correcting cam can be used.

As mentioned previously, the magnitude of the thyratron grid voltage must be large enough to compensate for variations in the critical grid voltage caused by usage and changes in temperature. It is possible to reduce the effect of these variations by replacing one of the thyratrons, figure 1, with a phanotron and to connect one side of the field circuit to the anode of the phanotron instead of to the midpoint of the anode transformer. In this way it is only necessary to control one tube. The secondary voltage of the anode transformer is the same in both cases. This circuit has the disadvantage that the secondary current flows only for one half the time and in only one direction. In addition the circuit is slower to respond for a decrease in excitation because of the short circuiting effect of the phanotron. The anode transformer can be eliminated if the power supply voltage has the correct value. The circuit characteristics are similar to those shown in figure 2.

In the control circuits just described the thyratrons were used to increase the field excitation. A failure of these tubes allows the motor to increase its speed to the value determined by the setting of the field rheostat. Even though the probabilities of a failure are rather remote, there are a few applications where it may be desirable to reduce the motor speed to its basic value if the thyratrons should fail to pass current. The elementary form of such a circuit is shown in figure 3. In this case the thyratrons control the field excitation indirectly

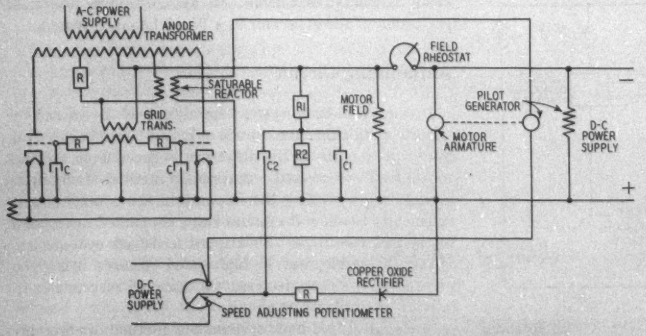

Figure 8. Thyratron field-control circuit, for holding constant speed

by varying the voltage drop in the field rheostat. With a failure of these tubes the motor speed will be reduced to its minimum value as determined by the setting of the field rheostat. The anode transformer must be designed correctly to limit the voltage applied to the field rheostat to such a value that the field current will not be reduced below its safe value, otherwise the motor will run away. The utility factor of this circuit is reduced because the change in motor field excitation is obtained indirectly. The maximum thyratron current will be approximately two times the rating of the motor field. The electrical characteristics of this circuit are shown by figure 4.

The elementary diagram of an armature control circuit in which the solenoid can also be used to vary the output voltage is shown in figure 5. The field excitation can be obtained either from a separate d-c source or from another pair of phanotrons which can use the same anode transformer for their source of voltage.

When armature control is used, some means must be provided to prevent impressing full voltage suddenly on the armature. In some applications this protection is taken care of by using a pair of contacts on the solenoid

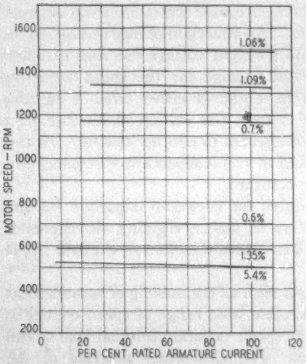

Figure 9. Characteristic curves of field-control circuit, figure 8, showing speed regulation for different speed settings

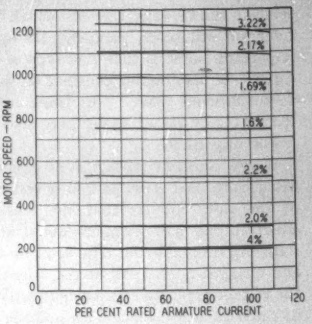

Figure 11. Characteristic curves of armature - control circuit, figure 10, showing speed regulation for different speed settings

that are connected in the coil circuit of an anode contactor and are closed only when the solenoid air gap is reduced to zero, corresponding to zero armature voltage. By means of an electrical interlock on the anode contactor, the contactor is held in the closed position after the motor is started.

If this method of protection cannot be used a standard d-c motor starter can be substituted. In either case protection against overload and loss of field excitation can be applied in the normal manner.

The characteristics of this type of control are shown in figure 6. A typical panel with two thyratrons for armature control and with two phanotrons for field excitation are shown in figure 7. An adjustable resistor is used in the phase-shifting bridge circuit to vary the range of control that can be obtained with the phase-shifting solenoid. The adjusting knob for this rheostat, the cathode time-delay relay, and the anode contactor are also shown on the front of this panel. The anode transformer and smoothing reactor are usually wall mounted.

These mechanical feed-back circuits have proved to be very useful in wire drawing, the making of celluloid, rubber and rubber fabrics, and other similar processes. In these applications the problem is to hold the tension constant as the material passes from one part to another part of the same machine, or from one machine to another, even though the driving speed of one part of the machine may vary. For example, if the material is being wound on a reel, it is necessary to change the speed of the reel-drive motor as the diameter increases. In this case the phase-shifting solenoid is mechanically connected to a rider roll which rests on the material. If the tension is above normal, the rider will rise, thereby changing the solenoid air gap, which in turn either increases or decreases the thyratron output voltage, restoring the motor speed to the correct value. If the reel-drive motor

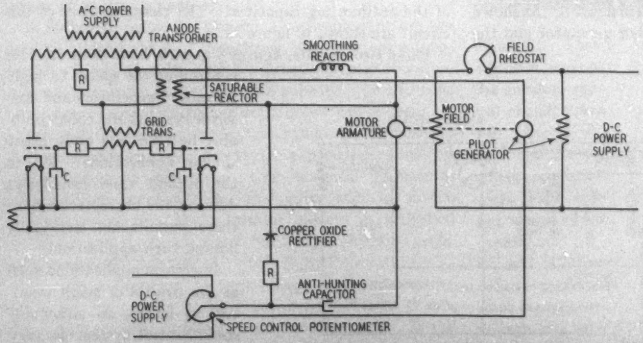

Figure 10. Thyratron armature-control circuit, for holding constant speed

tends to run too slow, the tension will be decreased and the rider roll will lower, producing the opposite effect. The important point is that this type of control not only is capable of maintaining constant tension but also provides a synchronous drive. In some applications constant tension is of minor importance and synchronism is of major importance.

Where constant tension is of importance the material being controlled must pass in a vertical plane either side of the rider roll so that the tension will always be equal to one half the unbalanced weight of the rider roll. In this case the only error is that due to friction and changes in the pull of the solenoid core. Normally the voltage applied to the solenoid coil is appreciably below its rated value for solenoid use and the change in pull from zero air gap to the maximum gap is less than two ounces and can usually be neglected.

Electrical Feedback—Saturable-Reactor Control

The previous discussion has covered the use of thyratrons for controlling either the field excitation or the armature power of d-c motors in which a mechanical feed-back control system has been used. There are many other applications where it is desirable to maintain constant speed, constant armature voltage, constant field voltage, to control a motor as some function of either a d-c or an a-c voltage, or to maintain approximate synchronism between two different systems by means of pilot generators. In the following circuits a small saturable reactor is used in place of the solenoid-type reactor. A suitable reactor is one that a change from zero to three milliamperes in the d-c winding will vary the reactance of the a-c winding from 1,000 to 10,000 ohms. If the a-c coils are connected in series this change in reactance can be obtained within a few cycles referred to a 60-cycle power supply. Since this reactor will have the same a-c impedance for a given saturating current of either polarity, it is necessary to limit current flow to one direction by connecting a unidirectional device such as a copper oxide rectifier or a rectifying tube in series with the d-c winding.

The elementary diagram of a field-control circuit for holding constant motor speed is given in figure 8. As shown the speed determining means is a pilot generator and the standard of reference is the voltage drop in a potentiometer. In normal operation the voltage of the pilot generator will be slightly greater than the voltage obtained from the potentiometer. If the load on the motor is increased the accompanying decrease in speed will be reflected by a decrease in the voltage of the pilot generator, which in turn will decrease the current through the d-c winding of the saturable reactor. This reduction in the saturating current will reduce the thyratron output or field voltage, thereby restoring the speed to approximately its previous value. If the load on the motor is decreased, the accompanying rise in speed will have the opposite effect. The speed never will be restored to exactly its previous value, when a change in load occurs, because there always must be a change in the relative voltages of the potentiometer and the pilot generator in order to produce the necessary change in the saturating current. With the correct saturable-reactor design a small voltage, when impressed on the d-c winding, is sufficient to vary the thyratron output voltage from zero to a maximum. By adjusting the arm of the potentiometer the speed of the motor can be held constant within a few per cent from no load to full load over its entire speed range as shown in figure 9. It will be noted that the change in speed from no load to full load for the lowest speed curve was between five and six per cent. This abnormal change was due to the fact that the thyratron output voltage was near its maximum value. The d-c voltage for the speed adjusting potentiometer can be obtained either from a suitable d-c voltage source or from the voltage of another pilot generator which is connected to another system. In this way the relative speed of two independent systems can be held approximately constant.

Hunting is prevented by means of capacitor $C2$ and resistor $R3$. Resistors $R1$ and $R2$ together with capacitor $C1$ have been added to reduce the effect of the field ripple voltage.

In certain processes such as the making of incandescent lamp bulbs an adjustable wide range of speed control is required in which the speed variation from no load to full load is a minimum. The elementary diagram of the armature control, figure 10, fulfills these requirements. Again the control elements are the same, including the use of the antihunting capacitor. The characteristics of this circuit are shown in figure 11.

These two circuits, figures 8 and 10, have been used for controlling the speed of high-frequency generators and conveyor systems and could probably be used in a great many similar applications. Up to the present time insufficient data on the characteristics of these circuits has materially limited their application.

In certain applications such as the control of small wood-turning lathes, an adjustable speed-control system is very desirable. The circuit shown

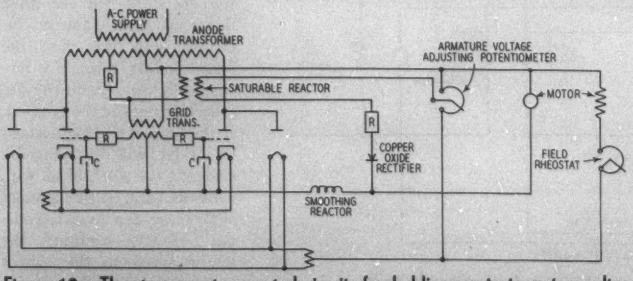

Figure 12. Thyratron armature-control circuit, for holding constant armature voltage

in figure 12 provides an adjustable source of power for the armature, and excitation for the field. The control circuit is the same as that shown in figure 10 except that the voltage applied to the speed-control potentiometer is obtained from the field circuit. Due to regulation in the anode transformer the change in speed from no load to full load is greater than that shown in figure 11. If better regulation is required, power for the potentiometer can be obtained from a separate direct current source or from a small rectifier. The effect of this regulation is shown in figure 13.

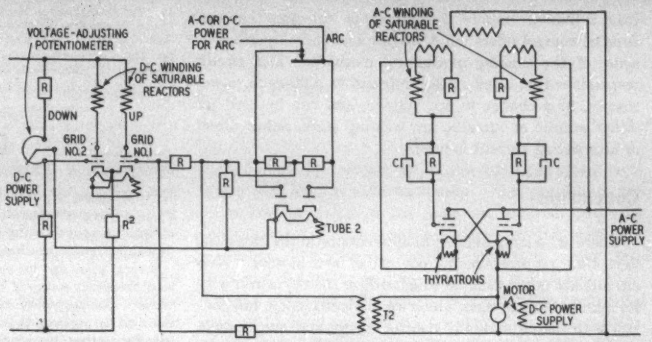

Figure 14. Thyratron control for reversing d-c motor—atomic or metallic arc-welding control

In all of the motor-control circuits which have been discussed the problem was primarily that of either maintaining a definite speed relationship between two systems or of maintaining constant motor speed. The third general classification is the control of a d-c motor as a function of either an a-c voltage or a d-c voltage which is dependent upon the speed or position of the motor. The control of either an arc furnace or an automatic arc-welding head fall in this class. The problem in either case is to maintain constant either the arc voltage or the arc current. The present mechanical method of arc-furnace control is to use either a contact making ammeter or contact making voltmeter together with reversing contactors. These contactors are required to operate a large number of times, consequently the wear is great. Somewhat the same situation applies for automatic arc welding heads but in addition either alternating current or direct current may be used. The circuit shown in figure 14 has been developed for either atomic or metallic arc welding. In this application a small d-c motor is used to feed the electrode wire to the arc. Since this motor is small only two thyratrons are required to run the motor in either direction while two pairs of thyratrons are required to control each motor of an arc furnace.

Referring to figure 14, two small saturable reactors are used to control the two thyratrons. With equal saturation in the two reactors each thyratron will pass the same amount of current, but of opposite polarity. In this case the average value of the torque in the motor will be zero. If the saturation of one reactor is greater than that of the other the motor will run in one direction at a speed determined by the difference in saturation. Conversely, if the saturation is in the reverse order, the motor will run in the opposite direction. The saturation current is controlled by means of a duotriode which has two anodes, two grids, and a common cathode.

In normal operation the arc voltage, either alternating or direct current, is rectified by means of tube 2 and impressed on grid number 1 of the duotriode. If the arc voltage is above normal, as determined by the setting of the voltage adjusting potentiometer, the saturating current through the "up" reactor will decrease, thereby reducing the current through the "up" thyratron with the result the motor armature will run in the down direction. The accompanying reduction in current through resistor *R*2 increases the bias on the grid number 2 in a positive direction tending to still further saturate the "down" reactor. If the arc voltage is low the "up" reactor will become saturated and the motor armature will run in the reverse direction. Due to the unbalancing effect of resistor *R*2 a variation of several per cent in the arc voltage is sufficient to cause the motor armature to run at full speed in either direction. In atomic welding the electrodes burn away so slowly that the motor armature normally stands still. In metallic arc welding the welding electrode burns away much faster and in normal operation the armature gradually turns in the downward direction, but can if necessary run from zero to full speed in either direction. While hunting is normally not present over-control is materially reduced by means of transformer *T*2, which introduces a retarding voltage into the grid circuit when a change occurs in the motor speed. The circuit will respond to a change in arc voltage within a few cycles referred to a 60-cycle power supply. Experience

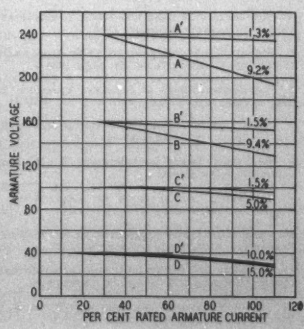

Figure 13. Characteristic curves of the armature-control circuit, figure 12. Curves A, B, C, and D show voltage regulation when field voltage was used for control. A′, B′, C′, and D′ show voltage regulation when separate d-c voltage was used for control

from a limited number of applications indicates that this type of control offers many advantages in comparison to some of the existing mechanical methods. This circuit responds within a few cycles, referred to a 60-cycle power supply, to a change in arc voltage, and can be used for either atomic or metallic arc welding when either direct or alternating current is used.

Conclusion

There are a large number of applications in the industrial field that require smooth control of d-c motors. New circuits are now available which utilize the thyratron with its inherent advantages which are high efficiency, full control with the minimum of control energy and quickness of response. The elements of these circuits are simple, easy to service, and of conventional design and consequently the circuits are easy to apply. It is possible by means of these circuits to maintain constant speed and constant relative speed between two systems. It is also possible to hold the voltage or current constant in an arc furnace or in an automatic arc welding head.

The use of these circuits in no way limits or alters the use of conventional d-c motor starting on protective systems. These circuits should not only be competitive, but should accomplish results that are difficult if not impossible to obtain with existing mechanical methods.

In the past, cost of the control and lack of confidence have been limiting factors in the application of thyratrons to the control of d-c motors. With increased use and refinements in design the cost will be reduced. Experience has already indicated that confidence in this type of control is increasing as thyratron control is being used with complete success at the present time in certain processes in which a failure of either the control or the thyratrons would cause a shut down of the entire system.

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Discussion

A. J. Williams, Jr. (Leeds and Northrup Company, Philadelphia, Pa.): I was much interested in Mr. Garman's paper, particularly in certain passages referring to antihunting devices which, however, I do not believe he mentioned in his oral presentation.

Several years ago my company had the problem of using a constant frequency source of low power level to control a d-c to a-c converter. One possibility was the use of a thyratron inverter, but for the type of application involved a motor generator seemed better suited since the tube capacity was less, since the output voltage could be made independent of d-c line voltage, and since a tube failure would cause only a loss of constant frequency and not a complete loss of voltage.

We used a shunt motor with thyratron control on the field. The thyratron was supplied with alternating current on the plate from the self-excited alternator and alternating current on the grid from the constant-frequency source. In operation, if the machine slowed down, the plate voltage increased its lag with respect to the grid voltage, more current was passed which weakened the motor field so restoring the phase in part and the speed completely.

We found that full-load variation could be taken care of readily but that the permissible variation in the d-c line voltage was not very great due to the inherent characteristics of a shunt motor with more or less saturation in the field. Anything which increased the range of line voltage stiffened the phase control and increased the tendency to hunt. There was a definite limit which could not be exceeded.

Our next step was to build in an antihunting system. I will not describe this. However, what I do want to mention is the very gratifying results which were obtained from the use of the system. The permissible variation in d-c line voltage was increased by a factor of four.

In closing, therefore, I want to repeat that I was much interested with the short passages in Mr. Garman's paper which referred to antihunting devices and from my own experience, I highly recommend their use for difficult control problems.

G. W. Garman: The prevention of hunting or its elimination as discussed by Mr. Williams, in any closely regulated system, can be a major problem in itself. It can be dealt with only in generalities, except in special cases where all of the constants of the system are known. In a large number of industrial applications, it is sufficient to hold the speed of the controlled motor within one of two per cent, as the load of the motor is varied from its no-load to its full-load value. In these applications hunting can be prevented by the methods illustrated in the paper. In those applications where the speed must be held constant within less than one-half of one per cent, the problem of hunting or of speed variation may become more serious, as other factors, which normally have little effect, now become of importance.

For example: Normally we think of the voltage of a d-c pilot generator as being continuous, except for the small ripple voltage produced by the commutator segments, the effect of which can be eliminated by means of a filter circuit as the equivalent frequency is high. However, the ripple voltage caused by an eccentric armature, even though it is very small, may be sufficient to produce an objectionable variation in the speed of the controlled motor. In addition, it may be difficult to determine whether motor speed variations of this type are caused by an unstable control circuit or by some other factor such as variations in the pilot generator voltage.

It is largely through experience that we learn to appreciate the effect of some of these factors, which normally are negligible, and therefore are able to solve satisfactorily these more difficult problems.

Electronic Speed Control of Motors

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IN THE EARLY years of the electrical industry there was no acceptable a-c motor. After the development of the induction motor and the synchronous motor two machines were available which are unsurpassed in simplicity, reliability, and economy. These motors are, however, both inherently constant speed machines. In later years, a variety of a-c motors have been developed and a number of these have had adjustable or variable speed characteristics. There is, however, as yet, no adjustable-speed a-c motor so flexible as the Ward-Leonard combination, and there is still room for much improvement in adjustable speed a-c motors.

The development of power tubes provides a new approach to the problem of variable-speed motors. This appears to be one of the most promising fields for large tubes and rapid progress may be expected in this direction. It is the purpose of this paper to outline briefly some of the more promising methods of using tubes to control the speed of a motor. A great variety of combinations may be produced, and there will be no attempt to give a complete discussion of this field. The arrangements described, are some of the simplest combinations and provide attractive characteristics.

Thyratron Motor

Those familiar with the art will recognize that a start has already been made in using power tubes to control the speed of an a-c motor. The first tube motor to be developed in America was constructed as a synchronous motor and employed a group of 18 thyratrons as a commutator.[1-3] The Appalachian Electric Power Company has been operating a 400 horsepower motor of this type for over one year. The characteristics and operation of this motor are fully discussed in other articles.[2-4] It is therefore not necessary to dwell further on this method of using thyratrons to produce an adjustable-speed motor.

Rectifier Speed Control for Wound-Rotor Induction Motor

The wound-rotor induction motor with secondary resistance has been used as an adjustable-speed drive in many applications. There are, however, two well-known disadvantages to this use of the induction motor: first, the efficiency of the motor is reduced in proportion to the speed reduction; second, the motor has poor speed regulation with load at reduced speeds. It is possible to improve the operation of this motor at reduced speeds by substituting a rectifier and d-c motor for the secondary resistance. This combination of induction motor, rectifier and d-c motor is quite similar to a Kraemer drive. The d-c motor may be used to help drive the mechanical load, or to drive an auxiliary a-c generator which returns, to the supply system, the power recovered from the induction-motor secondary.

Speed adjustment of the induction motor is obtained through the field of the d-c machine. The action is as follows: assume that the d-c motor in figure 1 is operating at constant speed and with a given field excitation. It has then a definite counter electromotive force and the rectified d-c voltage must match this before current can flow. The d-c voltage of the rectifier bears a definite ratio to the alternating voltage applied to the rectifier which, in turn, is determined by the slip of the induction motor. If, therefore, the a-c motor be operating at synchronous speed it must slow down until the secondary induced voltage is sufficient, when rectified, to match the voltage of the d-c machine. Any further reduction in the speed of the induction motor will cause a current to flow in its secondary and produce a corresponding induction-motor torque. In this manner the induction motor operates at an approximately constant speed or slip determined by the counter electromotive force of the d-c motor.

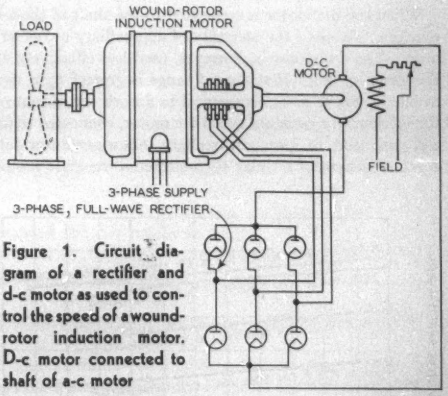

Figure 1. Circuit diagram of a rectifier and d-c motor as used to control the speed of a wound-rotor induction motor. D-c motor connected to shaft of a-c motor

It is evident from the unidirectional character of a rectifier that a small increase in the speed of the a-c

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1. For all numbered references, see list at end of paper.

motor does not result in a reversed torque. Dynamic braking will, however, occur if the speed of the induction motor exceeds the synchronous speed by a slip equal to the slip required for motor action.

Apparatus Economy

The principal advantage of the rectifier control arises from the fact that the operation and rating of the rectifier are quite independent of the frequency. The rating of the rectifier must approximately equal that of the induction motor. The size of the d-c machine however will be determined by the speed variation required. In case the d-c motor is connected to the same shaft as the a-c motor the approximate rating of the d-c motor may be obtained from the relation,

$$M = \alpha - 1 \qquad (1)$$

where α represents the ratio of the maximum to the minimum speed required and M, the ratio of the rating of the d-c and a-c motors. For a two-to-one speed ratio the d-c motor must equal the a-c motor in capacity.

When the d-c motor is connected to the shaft of the a-c machine, we avoid the necessity of an auxiliary a-c generator. The d-c motor is, however, used less effectively at the lower speeds. If the speed range is greater than two to one it will be more economical to absorb the output of the rectifier in a constant speed d-c motor, connected to an a-c generator, to form an auxiliary motor-generator set. A motor-generator set may be preferred if the main motor operates at a low speed or when its location is such that it is inconvenient to connect the auxiliary d-c motor to its shaft.

When an auxiliary motor-generator set is used M, the ratio of the rating of the d-c motor to the rating of the main motor is

$$M = \frac{\alpha - 1}{\alpha} \qquad (2)$$

where α as above is the ratio of the maximum to minimum speed. For a two to one speed control the d-c motor must be half the rating of the main a-c motor. The a-c generator in the auxiliary motor-generator set must be large enough to return the power recovered to the supply system. In case of a constant-torque load the a-c generator must have approximately the same rating as its d-c motor. If, however, the load torque decreases with speed as in a fan drive the a-c generator may be considerably smaller than the d-c motor. At high speeds the d-c machine delivers very little power because it has a weak field. At low speeds the d-c motor furnishes little power because it has a small current.

Wye-Delta Secondary Connection

When the load and therefore the current decreases as the speed is reduced it is possible to extend the range of speed control by changing the induction-motor secondary from a wye to a delta connection at some reduced speed. In this way a greater speed range may be obtained from a given d-c motor.

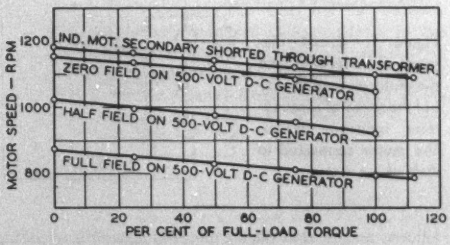

Figure 2. Speed-torque characteristics of a wound-rotor induction motor with rectifier speed control

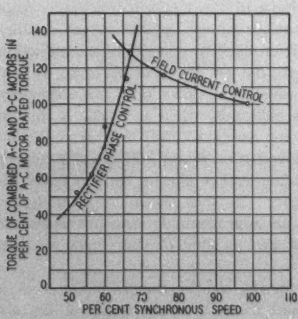

Figure 3. Torque available at rated current when induction - motor speed is reduced by rectifier and d-c motor connected to shaft of a - c motor. Speed control partly by d-c motor field and partly by rectifier phase control

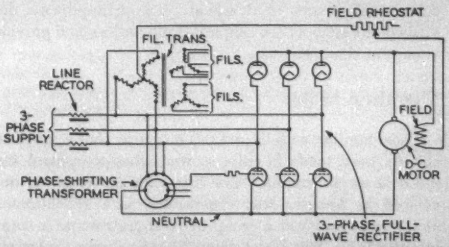

Figure 4. Circuit diagram of a d-c motor operating from a phase-controlled rectifier. Three-phase full-wave rectifier with half-wave phase control shown

Circuit Diagrams and Characteristics

There is given in figure 1 a circuit diagram for a three-phase full-wave rectifier as used to control the speed of a wound-rotor induction motor. The d-c motor is here shown connected to the shaft of the a-c motor. The same rectifier circuit may be used with an auxiliary motor-generator set. The curves on figure 2 show the speed-torque characteristics of the motor shown in figure 1. The speed-torque curves with an auxiliary motor-generator set are similar.

In taking data for the curves shown, a 25-horsepower

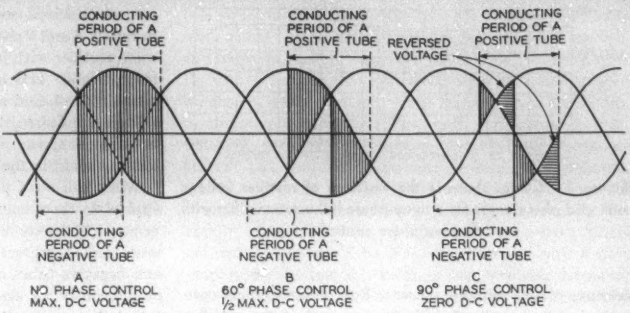

Figure 5. Curves showing the operation of a three-phase full-wave rectifier with full-wave phase control

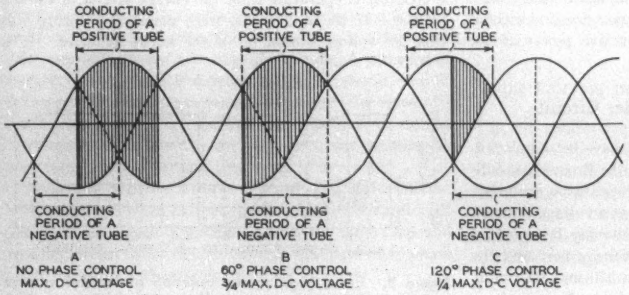

Figure 6. Curves showing the operation of a three-phase full-wave rectifier with half-wave phase control

motor with a 110-volt three-phase secondary winding was used. The secondary voltage of this motor was too low to rectify efficiently. This difficulty may be encountered in some motor designs, but it seems possible to obtain motors of 50 horsepower or greater with a secondary voltage high enough to rectify economically.

In the case of the 25-horsepower motor the secondary voltage was stepped up to 1,100 volts by means of auto-transformers. This device would be expensive and cannot be considered typical. The use of the transformers in the tests increased the full load slip somewhat but otherwise did not materially affect the operation.

Phase Control of Rectifier

It is evident that, by phase controlling the rectifier, it is possible to extend the range of speed control. The curves in figure 3 show the variation of torque with speed for an induction-motor control with constant effective current in the primary of the induction motor. In obtaining data for these curves the d-c motor was connected to the shaft of the induction motor. This accounts for the increasing torque available as long as the speed is reduced by motor field control. It is evident from the curve shown in figure 3 that the motor torque, available at rated current, decreases rapidly if the speed is reduced by phase control of the rectifier. When an auxiliary motor-generator set is used, phase control of the rectifier causes the main motor to operate even less effectively than as shown in figure 3.

Starting

When starting an induction motor which operates with a secondary rectifier for speed control, the starting current may be limited by series resistance in the a-c lines. A somewhat simpler arrangement would employ a resistance in the d-c lines. If there is an auxiliary motor-generator set which can be started before the main motor, no other starting device is necessary. The counter electromotive force of the d-c machine, acting with the inherent impedance of the induction motor will limit the starting current to a moderate value.

Phase-Controlled Rectifier and D-C Motor

The d-c motor has long been the standard of excellence as an adjustable-speed drive, but its use is limited because of the prevalence of a-c power. When a motor-generator set is used for converting from a-c to d-c power the Ward Leonard combination gives a flexibility and range of speed control difficult to equal. The cost or low apparatus economy of the Ward Leonard combination is its greatest limitation.

There is little or no novelty in supplying a d-c motor from a rectifier and varying the speed by field control. When, however, the motor and rectifier are considered as a unit, a new degree of freedom may be introduced in varying the armature voltage by phase control of the rectifier. This combination permits a greater range of speed adjustment than can be economically obtained by field control alone. In the upper part of the speed range where the power required is a considerable portion of the motor rating, field control is desirable because this will give the highest efficiency and power-factor. For the lower speed ranges, phase control of the rectifier, to give a reduced armature voltage is desirable. The low efficiency and power-factor produced by phase controlling the rectifier are of little consequence at the low speeds

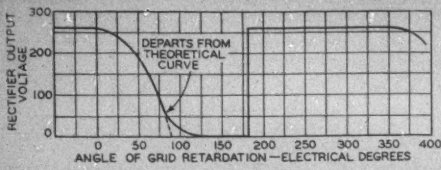

Figure 7. Curves showing the variation of rectifier voltage with grid phase angle for a three-phase full-wave rectifier with full-wave phase control

because of the reduced power. By combining field control of the motor and grid-phase-control of the rectifier it is possible to obtain a 100 per cent speed range (zero to rated speed) with a motor of moderate size, and without unduly increasing the losses and reactive power of the rectifier.

Three-Phase Full-Wave Rectifier Circuit

Any convenient rectifier circuit may be employed. Where three-phase power is available the three-phase full-wave rectifier circuit gives the best apparatus economy. If the three-phase power is available at a voltage between 220 and 600 volts, this rectifier circuit may be operated from the a-c lines without rectifier transformers and the d-c voltage produced will be between 250 and 800 volts. The full-wave rectifier is penalized at low voltage by having two tubes in series and therefore a high arc drop loss. This objection is, however, more than compensated for, by the elimination of rectifier transformers, even though the operating voltage is as low as 220 volts.

The rectifier should be connected to the a-c power supply through line reactors as shown in figure 4. These reactors are very useful in suppressing current and voltage harmonics, and also serve to limit the fault current in case of an arc back or other failure. The three-phase full-wave circuit is attractive in view of the fact that line reactance is twice as effective in limiting the short-circuit current of the a-c system, as in producing regulation of the d-c voltage. A ten per cent reactance in the a-c lines produces only five per cent regulation of the d-c voltage, but limits the current to ten times normal in the case of a three-phase short-circuit.

Half-Wave Phase Control

In the circuit diagram shown in figure 4, phase control is applied to only half of the rectifier tubes. This arrangement is quite desirable. For lack of a better description this operation may be called half-wave phase control of a full-wave rectifier. This method of phase control is superior to the full-wave phase control where all tubes are controlled, in that it produces lower reactive kilovolt-amperes and smaller harmonic currents in the a-c supply system. The advantages of half-wave phase control are greatest at low d-c voltage.

The operation of a rectifier with half-wave phase control is best explained by comparison with full-wave phase control which is somewhat simpler. The curves given in figures 5 and 6 show the operation of a three-phase full-wave rectifier with full-wave and half-wave phase control, respectively. It is important to note that with full-wave phase control, and more than 60 degrees phase shift the voltage applied to the d-c circuit reverses during part of the time as shown in figure 5*C*. This causes low power-factor current in the a-c circuit.

When half-wave phase control is employed the voltage applied to the d-c circuit may go to zero but it never reverses. If the conducting period of the tubes is delayed more than 60 degrees there comes a time when the positive and negative tubes of the same phase are conducting simultaneously as shown in figure 6*C*. During this interval the a-c circuit is effectively disconnected, and the d-c circuit is operating from the energy stored in the d-c reactor. If the a-c circuit were connected during this time its voltage would be of the wrong polarity. It is

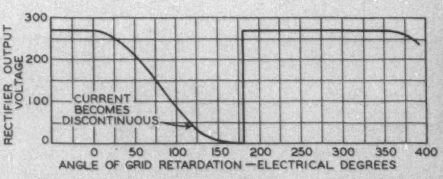

Figure 8. Curve showing the variation of rectifier voltage with grid phase angle for a three-phase full-wave rectifier with half-wave phase control

therefore better that the a-c circuit be effectively disconnected.

When a three-phase full-wave rectifier with full-wave phase control is employed E_{dc} the d-c voltage is given approximately by the relation

$$E_{dc} = 1.35\ E_L \left(\cos\theta - \frac{XI}{2I_0}\right) - 2e_t \qquad (3)$$

where E_L is the effective a-c line voltage, θ is the angle by which conduction of the tubes is delayed by grid control, e_t is the arc drop of one tube, I_0 is the rated current, I is the actual current in the d-c circuit, and X is the per-unit reactance in the a-c lines. It is evident from this relation and from the curves of figure 5 that the d-c voltage is zero when the phase shift θ is 90 degrees. The relation (3) assumes that the current in the d-c circuit is continuous but it is evident that as the d-c voltage is decreased the ripple voltage increases. The current in the d-c circuit will, therefore, become discontinuous at some reduced voltage, depending on the size of the d-c reactor and the load current. The average voltage in the d-c circuit will then depart from the curve determined by relation (3), because this relation assumes a continuous current and does not hold when the current is intermittent.

Figure 7 shows a typical phase-control curve for a three-phase full-wave rectifier operating with full-wave phase control. The data for the curve was taken with a re-

sistance load in the d-c circuit. If there had been a counter electromotive force load the current would have become intermittent at a higher voltage.

When the voltage applied to the grid circuit of the tubes is sinusoidal a phase shift of more than 180 degrees causes the tubes to be started at the normal time by the lagging tip of the grid-voltage wave. A phase shift of more than 180 degrees therefore, restores full d-c voltage, as shown in figure 7.

When a three-phase full-wave rectifier is operated with half-wave phase control, E_{dc} the d-c voltage is given approximately by the relation.

$$E_{dc} = 1.35\,E_L\,\frac{\left(\cos\theta+1\right)-X\,\frac{I}{I_0}}{2}-2e \qquad (4)$$

where, as above E_L is the effective a-c line voltage, θ is the angle by which the conduction of the tubes is delayed by grid control, e_t, is the arc drop of one tube, I_0 is the rated current, I is the actual current in the d-c circuit, and X is the per unit reactance in the a-c lines. In case half-wave phase control is employed the grids must be shifted 180 degrees to reduce the d-c voltage to zero, as may be seen from relation (4) and the curves of figure 6.

The curve of figure 8 shows the variation of d-c voltage with grid angle when half-wave phase control is employed. The data for figure 8 was taken with the same load and rectifier circuit as for figure 7, except that half-wave phase control was used when taking data for figure 8.

It is evident from the curve in figure 8 that with a sinusoidal grid voltage full d-c voltage is restored by a grid shift just a little greater than that necessary for zero d-c voltage. This becomes a hazard when operating at a very low d-c voltage, unless some type of self-biasing grid circuit be used so that the positive voltage wave on the grid is shorter than the negative voltage wave. Even with a self-biasing grid circuit too great a phase shift will cause the d-c voltage to increase abruptly to its maximum value.

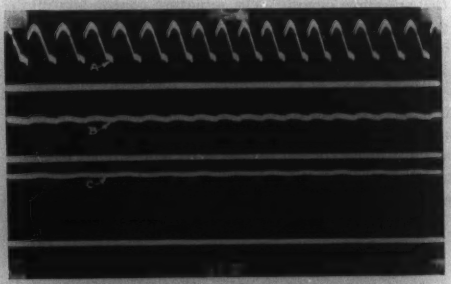

Figure 9. Oscillogram showing voltage impressed on motor field, trace A, field current, trace B, and voltage induced in armature at rated speed, trace C, when the field of a d-c motor is supplied from a three-phase half-wave rectifier

A possible objection to the use of a rectifier with half-wave phase control arises from the fact that the positive and negative current waves are not symmetrically spaced. Either the positive or negative current wave is displaced because of phase control. This leads to even harmonics in the supply current. These even harmonics do not, however, increase the effective value of the harmonic current but the even harmonics replace odd harmonics which would be present if the rectifier were operated symmetrically. The resulting harmonic current in the supply circuit is never greater with half-wave phase control than it would be if full-wave phase control were employed. At low d-c voltages the resulting harmonic current is lower with half-wave phase control than with full-wave phase control. With this picture of the operation of half-wave phase control we may return to a consideration of a d-c motor operating from a phase-controlled rectifier.

Ripple Current in Armature Circuit

If the conducting period of a rectifier is delayed by grid control, the average voltage in the d-c circuit is reduced but the deviation of the instantaneous voltage from the average or d-c voltage is greatly increased. This deviation of the instantaneous from the average voltage is usually referred to as the ripple voltage. The increase of ripple voltage with phase control is obvious in figures 5 and 6. The ripple voltage produced by the rectifier causes a current ripple in the d-c load circuit. An inductive reactance is frequently used to reduce the magnitude of this ripple current.

When the phase-controlled rectifier is supplying a d-c motor, commutation will limit the magnitude of the ripple current permissible. The inductance required for the d-c circuit may be determined from the relation

$$L = \frac{E_r}{\frac{dI_{am}}{dt}} \qquad (5)$$

where

E_r = the maximum ripple voltage produced by the rectifier; $\frac{dI_{am}}{dt}$ is the maximum rate of change of armature current consistent with good commutation.

The maximum permissible rate of change of armature current can be determined from the motor design.

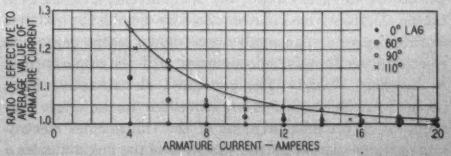

Figure 10. Curve showing ratio of effective to average value of armature current when a d-c motor is supplied from a three-phase full-wave rectifier with half-wave phase control

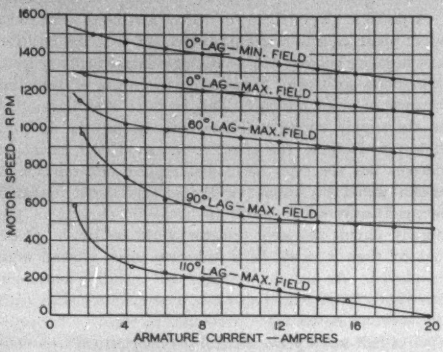

Figure 11. Speed–armature-current characteristics for a d-c motor operating from a three-phase full-wave rectifier with half-wave phase control

Field Excitation for D-C Motor

When operating a d-c shunt motor from a phase-controlled rectifier it is important that the field of the motor be supplied from a reliable source at a constant voltage. It is possible to supply the field from an auxiliary rectifier with a suitable interlock for removing the armature voltage if the field power fails. A more convenient source of field excitation is, however, available when half-wave phase control is used. It is then possible to connect the field between the a-c neutral and the d-c line common to the three tubes not phase controlled. This connection is shown in figure 4.

If the a-c system has no neutral, an artificial neutral can be created by the filament transformers, phase-shifting transformer, or other auxiliary equipment. It is desirable to have the transformers forming the artificial neutral, connected zigzag to avoid saturation.

When the shunt field is supplied by connecting it from the a-c neutral to one d-c line, the voltage impressed on the field will have a triple-frequency ripple of considerable magnitude. This ripple voltage will, however, cause only a small variation in the field current because of the high inductance of the field circuit. Eddy currents set up in the poles and frame of the d-c machine will further neutralize the small ripple present in the field current and maintain the flux through the field sensibly constant. The oscillogram in figure 9 shows the voltage impressed on the field circuit, the field current, and, the generated electromotive force obtained by driving the machine at rated speed. The small ripple shown on the generated electromotive force is not concurrent with the ripple current in the field circuit. The generated electromotive force shows no evidence of flux variation due to the ripple current. A direct measurement of the transformer electromotive force caused by the variation of the flux indicates a voltage of the order of 20 to 50 millivolts in the coil under commutation. An effect of this magnitude will have a negligible influence on commutation.

In case a series field winding is employed, the ripple current in this winding will also tend to produce variations of the flux. Measurements made with a ten per cent series field indicate a transformer electromotive force in the coil under commutation no greater than that caused by the ripple in the shunt-field current; i.e., 20 to 50 millivolts. With a larger percentage of series excitation the ripple current in the series field will be correspondingly reduced by the inductance of the series field. It appears, therefore, that no appreciable commutating trouble may be expected from field-flux variation with either shunt or series field excitation.

Operating Characteristics

The operating characteristics of a d-c motor are quite familiar. When, however, the d-c motor is supplied from a phase-controlled rectifier there are certain modifications introduced by the rectifier. It, therefore, seems desirable to give some operating data. The curves shown in figures 10 to 13, inclusive were taken on a 10-horsepower 550-volt 1,300-rpm d-c shunt motor operating from a three-phase full-wave rectifier with half-wave phase control. The circuit diagram is as shown in figure 4. The rectifier was supplied from a 440-volt, 3-phase, 60-cycle source of power. A picture of the rectifier and its associated equipment is shown in figure 14.

The curves shown in figure 10 give the ratio of the effective to average value of the armature current. The ripple current in the armature contributes nothing to the power of the d-c motor but increases the copper loss of the armature circuit. The armature copper loss of the d-c motor will be increased approximately as the square of the ratio of effective to average current shown in figure 10.

The ripple voltage increases rapidly as the d-c voltage is reduced by grid control, but does not vary appreciably with the load. It is evident, therefore, that with a given angle of phase control the ripple current is fairly constant and independent of the load current. At light loads the ripple current will exceed the load current, with the result

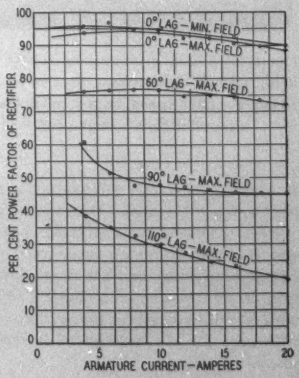

Figure 12. Power-factor curves for a three-phase full-wave rectifier with half-wave phase control. Rectifier used to supply a d-c motor

that the armature current will become intermittent. It is this condition which causes the high ratio of effective to average current at light loads. Fortunately this pulsating armature current does not cause undue motor noise or vibration when the rate of change of armature current is kept within the limit required for satisfactory commutation.

The curves in figure 11 show the variation of speed with load, or armature current. These curves show that the motor has considerable speed regulation largely because of the reactance in the a-c supply lines. When phase control is employed to reduce the motor speed, the speed regulation at light loads is quite large. This is due to the intermittent armature current at light loads. Where less speed regulation is required this may be obtained by using less line reactance or by a number of methods of compounding the rectifier to give a grid-phase shift in response to load. It is undesirable to operate with a very low a-c line resistance because this will increase the harmonic currents present in the a-c supply and lead to more severe fault currents in case of an arc-back.

Power-factor curves are shown in figure 12 for several grid phase angles, selected to reduce the d-c voltage by steps of about 25 per cent. The data for these power-factor curves was taken with 20 per cent reactance in the a-c lines. It is unlikely that a reactance greater than this would be used.

When the rectifier is operating to give full d-c voltage and with about 20 per cent a-c line reactance the power-factor is about 90 per cent with zero grid angle; and this power-factor is maintained even at light loads as may be seen from figure 12.

If the motor speed is reduced by phase control the power-factor of the rectifier is affected quite adversely. At low speed the decrease in power-factor caused by full-wave phase control is even more than that shown in figure 12.

The reduction of power-factor caused by phase control is one of the important reasons for using motor-field control for part of the speed range. It seems desirable to use motor-field control to reduce the speed until the power required by the motor is not greater than half the full-load power at maximum speed. This corresponds to a 50 per cent speed reduction for a constant-torque load and about 20 per cent speed reduction by field control for a variable-torque load such as a fan. If the motor speed is reduced by field control until the motor power is reduced to half its maximum value the reactive and harmonic power required by the motor will never exceed that required at full load.

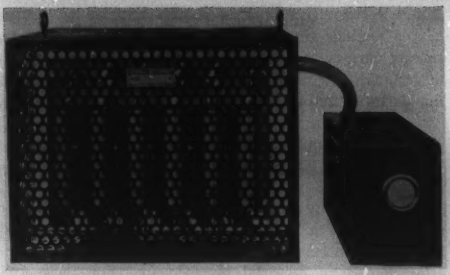

Figure 14. Picture of three-phase full-wave rectifier and associated equipment as used for controlling the speed of a 10-horsepower 1,300-rpm 550-volt d-c motor. One hundred per cent speed range provided, partly by field control and partly by phase control of rectifier

Efficiency curves are shown in figure 13. These curves are taken for the same conditions of operation as the power-factor curves of figure 12. The efficiency as shown in figure 13 applies to the rectifier only and does not include the motor losses. Since motors may vary considerably in efficiency it seems best to give rectifier efficiency separated from the motor efficiency. The very low efficiencies found at low speeds, result from the fact that the major rectifier loss is caused by the arc drop of the tubes which is approximately a constant voltage drop. As the d-c voltage is reduced by phase control the arc drop represents an increasing proportion of the total power. It should be recognized that the rectifier efficiency will be lower, if a lower a-c supply voltage is employed.

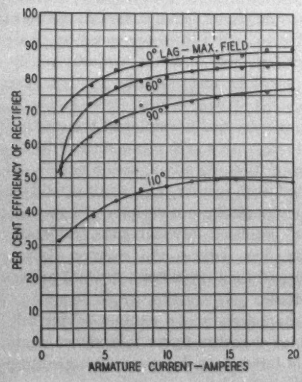

Figure 13. Efficiency curves for a three-phase full-wave rectifier with half-wave phase control. Rectifier used to supply a d-c motor

Starting, Reversing, and Braking

Any means of motor speed control which permits the motor to be operated at very low speeds provides the requirements essential for starting. Phase control of the rectifier gives the control necessary for starting the motor and accelerating it smoothly, without producing abnormal currents. A suitable interlock between the phase-shifting transformer in the grid supply and the contactor in the motor circuit will prevent an improper starting sequence.

If a simple rectifier circuit is employed, the unidirectional conductivity of the rectifier necessitates the reversal of the motor connections, either armature or field, when the motor is to be operated in a reverse direc-

tion. Regenerative braking is also impossible when a simple rectifier circuit is used because there can be no reverse current to decelerate the motor. When regenerative braking or rapid reversal of the motor is required a double tube-circuit should be employed as shown below.

D-C Motor Operated From a Reversible Electronic Converter

There are many motor applications which require either rapid reversal or regenerative braking. Elevators and hoists are two examples, typical of the service where deceleration is an essential requirement. For these and many similar applications, a d-c motor operating from a simple phase controlled rectifier, is inadequate as was pointed out above. It is possible, however, to add the regeneration braking feature, by the addition of a duplicate set of tubes connected for reverse current and with their grids excited for inverter operation.

Regenerative Braking

The circuit diagram in figure 15 shows a double set of tubes with a single-phase a-c supply. One set of tubes is connected for reverse current, which is essential for regenerative braking. The operation may be explained as follows: assume that the *A* group of tubes is rectifying and furnishes current to drive the motor in a clockwise direction. Should the d-c motor be overspeeded a little, the motor counter electromotive force will exceed the rectified voltage and no current can then flow from the rectifier. The *A* tubes are then inoperative.

If the inverter tubes, the *B* group, as shown in figure 15, are properly adjusted a small increase in the counter electromotive force of the motor will be sufficient to cause them to begin inverting. They will then draw power from the motor, causing it to operate as a generator with the corresponding retarding torque. The power delivered by the d-c machine is transferred to the a-c system through the *B* group of tubes acting as inverters.

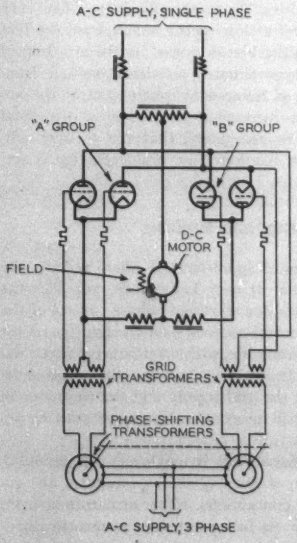

Figure 15. Circuit diagram for a reversible electronic converter for supplying a d-c motor

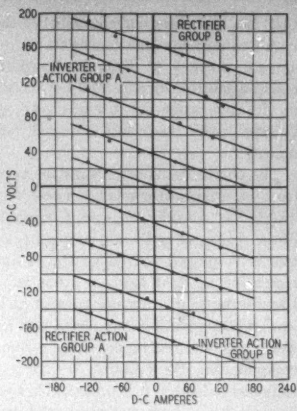

Figure 16. Curves showing the variation of d-c voltage with load current for a reversible electronic converter

There is of course some speed regulation with load for both the rectifier and inverter tubes. With rectifier or driving operation, the speed regulation is positive and the motor speed decreases with increasing armature current. For inverter or braking operation, the speed regulation is negative, and the motor speed increases with increasing armature current. The curves shown in figure 16 are typical speed armature-current characteristics as the motor operation is changed from braking to driving.

Reverse Rotation by Phase Control

The action as explained so far would permit the motor to operate at an approximately constant speed over a load range, from full driving to full braking. A constant speed application which requires regenerative braking is, however, seldom if ever encountered. Speed variation and reversal are essential in most applications which require braking. With the circuit arrangement as shown in figure 15 it is possible to vary the motor speed by phase controlling the rectifier and inverter simultaneously. Full-wave phase control is most satisfactory for this service.

When full-wave phase control is employed the rectified voltage is reduced to zero by a grid phase-shift of 90 degrees as is shown in relation (3) and figures 5 and 7. If the grids be retarded still further, the rectifier will be found to have a counter electromotive force and may operate as an inverter. Similarly, advancing the grid phase-angle of an inverter first reduces the counter electromotive force to zero and then produces a forward or rectifier electromotive force.

The grid-control characteristic of a rectifier having full-wave phase control, as shown in figure 7, is shown again in figure 17. In the latter case, however, the operating

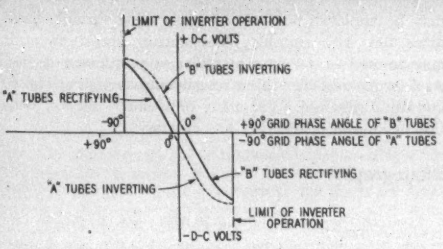

Figure 17. Curves showing the variation of d-c voltage with grid phase angle for a reversible electronic converter

curve of both the *A* and *B* tube groups are shown, and the rectifier phase-control curve is extended to show the inverter range. It is evident from an inspection of figures 15 and 17 that the distinction between inverter and rectifier operation is largely a question of the relative phase of current flow in the a-c circuit. The principal difference arises from the change of the voltage stress across the tube from negative to positive as the operation is changed from rectifying to inverting. The positive tube voltage in the inverter region necessitates a negative grid bias during the entire non-conducting interval. Assuming a suitable grid excitation, however, a group of tubes will function as either a rectifier or inverter. Such a tube group is conveniently and accurately described as a converter.

When the tube converter employs natural or phase commutation, its operating range covers only about 180 electrical degrees. Phase control as a rectifier is then possible only by retarding the phase of the grids. There is a commutating voltage in inverter operation only if the current transfer takes place before the voltage of the incoming phase equals the voltage of the outgoing phase. Fortunately the rectifier and inverter quadrants are adjacent and we may pass from rectifier to inverter action or conversely by a continuous shift of the grid phase-angle.

If the d-c voltage of a rectifier is to be reduced, the grids of the rectifier tubes should be retarded. The opposite is true for an inverter, and the grids of the inverter tubes should be advanced to reduce the operating voltage.

For this reason separate phase-shifting transformers are required for the *A* and *B* tube converters. These two phase-shifting transformers may however be rigidly coupled and moved simultaneously if they are so arranged that the electrical rotation of one is opposite to the other. This is indicated on figure 17 by showing reversed scales for the grid phase-angle of the two converters.

If the phase control characteristic of the *A* and *B* converters are displaced as shown in figure 17, the operating voltage of the inverter will exceed the rectifier voltage for both directions of rotation and there will be a "discrepancy" or change in motor speed when changing from driving to braking. This phenomena can be eliminated by proper alignment of the two phase-shifting transformers. Should the inverter be set for an operating voltage below the rectifier voltage, there will be a circulating current between the rectifier and inverter and corresponding losses. A small circulating current is desirable when a motor speed "discrepancy" between driving and braking is objectionable.

When the phase-shifting transformers are displaced beyond the safe operating limits the tubes acting as inverters lose their commutating voltage. This results in a short circuit between the two converter groups, and should therefore be avoided.

With a circuit arrangement as shown in figure 15 and suitable grid excitation for both the *A* and *B* converters, as discussed above, the motor speed can be controlled through a speed range from full speed forward to full speed reverse. The control required is only a movement of the phase-shifting transformer. At all speeds, forward and reverse, the motor will give regenerative breaking if over-speeded. With the phase-shifting transformers in any operating position there is a speed armature-current characteristic, similar to those shown in figure 16.

The combination of d-c motor and reversible converter just described, is quite flexible and has a very sensitive control in the phase-shifting transformers. This arrangement appears suitable for many applications which have formerly required a Ward Leonard set.

Torque Amplifier

The sensitive and accurate control permitted in the grid circuit of the converters of the motor just described adapt

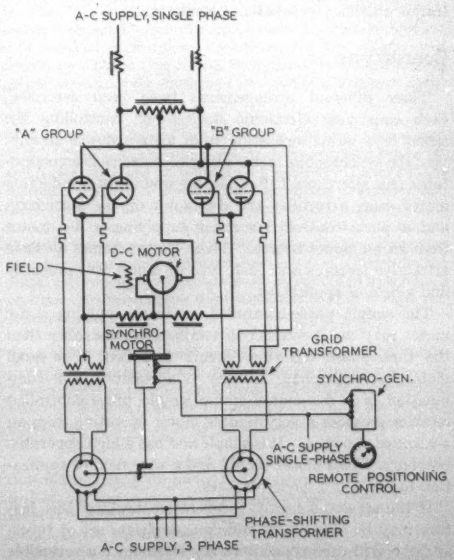

Figure 18. Functional diagram for a torque amplifier employing a d-c motor and a reversible electronic converter

it to many applications not adequately served by a Ward Leonard combination. The arrangement shown in figure 18 gives a scheme for producing a torque amplifier or positioning device. The only change required from the circuit of figure 15 is that the two phase-shifting transformers, which supply the grid power are not manually operated as in figure 15, but are connected to both the positioning control and the main motor, in effect, as through a differential. Referring to figure 18, a displacement of the positioning control acts through the synchro-motor to cause a movement of the grid phase-shifting transformers. This grid shift sets up a current causing the main motor to move. The main motor is connected to the stator of the synchro-motor through a gear. The rotation is such that a movement of the main motor produces a phase shift which cuts off the current causing the motor to move. Therefore, when the main motor has moved through an angular displacement corresponding to the displacement of the position control, the main motor will have corrected the grid phase-displacement which was caused by the movement of the positioning control. In this manner the main motor is kept in close correspondence with the positioning control. If the controlling device is kept in continuous motion, the motor is compelled to follow in a corresponding angular position, but the load or torque burden on the positioning control is only a slight portion of the torque exerted by the main motor in driving its load. The grid control is so accurate and rapid that very close correspondence is maintained between the motor shaft and the positioning device. Automatic tools offer an attractive field of application for a reversible electronic converter arranged to operate as a torque amplifier or position control.

Conclusions

Three different arrangements have been described, each employing electronic devices for controlling the speed of a motor operating from an a-c power supply: viz., the synchronous motor using thyratrons as a commutator (see references 1, 2, 3, 4), the wound-rotor induction motor using a rectifier and d-c motor on the secondary, and a phase-controlled rectifier supplying a d-c motor from an a-c power source. These three schemes all have attractive features and each type of motor will probably find a field of application.

The simple phase-controlled rectifier supplying a d-c motor may use a number of rectifier circuits other than the three-phase full-wave circuit described. For small motors a single-phase rectifier is adequate. The combination of a d-c motor and a simple phase-controlled rectifier provides a very flexible motor operating from an a-c source of power. It is simple and has a high apparatus economy. This motor should find a wide field of application in small and moderate sizes.

If the service demands regenerative braking this feature may be secured by adding a duplicate set of tubes, and the grid excitation necessary to produce a reversible electronic converter.

The combination of d-c motor and reversible converter, may be employed not only as a reversible variable-speed drive but with suitable phase-shifting transformers, it may be used as a torque amplifier or positioning device. As a torque amplifier this arrangement has high precision, and rapid response. For many problems it offers a solution unequaled in accuracy and elegance.

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Discussion

E. F. W. Alexanderson (General Electric Company, Schenectady, N. Y.): Our paper has the object of indicating some of the many possible applications of electron tubes for power transformation. Specifically, it deals with the controlled rectifier, inverter and frequency changer as a power supply for motors. It has not been possible to include in this discussion all the combinations that we have in mind. There is, for instance, one combination which we should like to include and which recent tests indicate to be one of the most promising. This is to absorb the secondary power of the induction motor in a thyratron frequency changer and return the energy to power lines. This combination requires eight tubes if a quarter-phase motor secondary is used.

At this stage is may be interesting to forecast how high motor powers may be conveniently operated by such methods. We may assume that tubes of 200 amperes average capacity will be available. It may also be assumed that the induction motor secondary is wound for 2,300 volts. Such a combination will control a motor of 4,500 horsepower. In this electronic technique we are by the nature of the problem compelled to analyze our expectations for the near future even though the ways and means to meet them are not available for the moment. There is a good reason for this. The basis for this work is the electron tube itself around which all the rest of the apparatus must be designed. But a development of high-power electron tubes is a long and expensive process. To furnish the incentive for this, it is necessary that the electrical engineers who deal with power problems both in design and operation should analyze their needs so that they will be able to point out the directions in which such development will show economic advantages. We hope that a discussion of the subject by the Institute will serve this purpose.

C. C. Shutt (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): The authors present an interesting and timely paper on the subject of electronic speed control. It is of particular interest to note that the authors have given considerable space to the wound-rotor type of machine with secondary control. For several years the writer has considered this arrangement preferable to the authors' earlier schemes, which used primary frequency control and a synchronous-type motor, for the following reasons:

1. The number of tubes is reduced and their connections simplified. Only one electronic power conversion required when d-c machine is used as described.

2. A practically standard motor is used with normal densities in copper and iron.

3. At reduced speeds the power factor can be practically as good as with resistance control.

4. Unless the speed reduction is large, the kilowatt rating of the tubes is reduced by the use of secondary control.

With these features in mind, a 350-horsepower unit has been built, which was designed primarily for a fan drive. It uses grid control on the tubes for the lower portion of the speed range. The advantage of grid control for such a drive is that the reduction of the d-c voltage reduces the flux required in the d-c motor at the lower speeds, and thus reduces the size of this machine. It will be recognized that this reduction of d-c voltage is accompanied by an increase in direct current and the current in the secondary of the induction motor. But, with a fan type drive, the current is still well below the rating of the windings at the low speeds. The use of grid control causes a reduction of primary power factor at low speed. But this is not objectionable at light loads which accompany low speeds on a fan drive.

A 1,250-horsepower, 1,200-rpm unit is now under construction.

In common with a Kramer drive, and other forms of secondary control, the drive will develop a maximum of practically constant horsepower when the secondary power is recovered in a d-c motor on the main shaft. It will develop a maximum of practically constant torque when the secondary power is recovered by some other means. These statements assume that the induction motor is worked at normal flux and current densities at all speeds. The equations 1 and 2 of the authors' paper appear to be based on this assumption.

Attention is called to the second sentence of the section under "Apparatus Economy." The authors state "The rating of the rectifier must approximately equal that of the induction motor." This statement is also based on the same assumptions as equations 1 and 2, the correctness of which depends upon whether the tubes are rated in current or kilowatts. Under the authors' assumptions, the tube current is constant regardless of the speed. Neglecting grid control—and it would probably not be used under these assumptions—the d-c voltage increases as the speed decreases. Hence, the kilowatt rating of the tubes is a function of the speed reduction, and certain types of tubes have higher current rating at reduced voltage. Hence, smaller tubes can be used with limited speed reduction.

In closing, the writer would point out that the relatively simple circuit consisting of an induction motor with a rectifier and d-c machine in the secondary only scratches the surface of the possibilities of this type of variable speed drive. Other types of electronic secondary control have been investigated for a range of applications and will be presented in the near future.

L. A. Kilgore (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): This paper gives a good description of several circuits which may be used for a-c variable-speed drives employing electronic tubes, but the description of the motor requirements is confusing at certain points. Equations are given for the relation between d-c and a-c motor ratings. These equations are misleading because they are only applicable to one special type of load, but which special case they are intended to cover is not stated.

Under the heading of "Apparatus Economy" the ratio of d-c motor rating to a-c motor rating is given in equation 1 as: the ratio of maximum to minimum speed minus one, for the case of a d-c motor connected to the same shaft as the a-c motor. This relation would only be true for the special case of constant power; also the ratings would have to be based on the minimum speed.

Also equation 2, which applies to the case where the secondary power is fed through a rectifier to a d-c motor of a motor generator set, is only applicable to the case of constant power; furthermore, it would seem that a maximum speed equal to synchronous speed had been assumed.

The general idea of a rectifier applied to the secondary of a wound-rotor motor to furnish power either to a d-c motor on the same shaft or to be fed back into the line is old, but very little use has been made of it in the past. However, with the recently developed thyratron and ignitron tubes, this type of variable-speed drive holds real promise. One place where it is particularly applicable is in the drive of large fans. For this case, smooth speed control from zero to 90 per cent of synchronous speed is possible with a d-c motor rated only about 40 per cent of the total power required at full speed, and for ignitrons the rectifier rating would be approximately 60 per cent of the maximum power output if the capacity is based on the increased voltage rating at low speeds.

Grid-controlled rectifiers have been used for some time for the purpose of speed control of d-c motors with or without the use of field control of the motor. The authors put particular emphasis on the full-wave three-phase circuit, which avoids the use of a transformer when a suitable a-c voltage source is available. Besides the advantages mentioned by the authors, this circuit has the additional advantage where the blocking of grids or ignitor circuits may be used to interrupt the a-c supply to an arcback, for unless a tube in both groups arcs back at the same time, there will be no back feed from the d-c motor.

The authors show some improvement in power factor at low d-c voltages for the particular arrangement which they call half-wave phase control of the full wave rectifier. However, this is accomplished at the expense of an increase of the magnitude of, and the introduction of, lower frequency components in the d-c voltage ripple. It may be found that where improvement in power factor is desired, it can be obtained more economically some other way.

J. H. Cox (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): This paper constitutes a *review of several methods* of controlling the speed of motors by electronic means, and as such is a valuable contribution. However, since the paper *mentions only thyratrons* as the electronic device to be used, and since thyratrons are only practical in relatively small sizes, the inference is left that this method of speed control is only applicable in small capacities. *Actually, the group with which I am associated* has carried out tests with a 350-horsepower drive using a similar method of control and is now building a 1,250-horsepower drive.

Throughout the paper the authors' choose the *three-phase full-wave circuit* and this circuit is much more convenient for this application than the more conventional power rectifier circuits, though the latter are somewhat more efficient. However, the three-phase full-wave circuit demands that the *cathodes associated with at least three* of the anodes be separated from the others and *there are serious objections* to building the conventional metal tank rectifier in single-anode tanks. However, *ignitrons are normally built in single-anode units*, and where no vacuum pumps are required they are amenable to any electrical circuit desired. Therefore, the methods of speed control described by the authors are now conveniently available up to sizes requiring electronic power that can now be provided by ignitrons with sealed-off construction. As mentioned in Mr. Kilgore's discussion, for a blower type of load, the electronic capacity required is only 60 per cent of the maximum power output at maximum speed.

W. R. King (nonmember; General Electric Company, Schenectady, N. Y.): I am particularly interested in the system described by the authors for controlling the speed of a d-c motor by means of a phase-controlled rectifier. I have had some experience in applying electronic equipment to the control of d-c motors and in the past have been forced to conclude that, primarily for economic reasons, the electronic systems were limited to the field of applications where some very special motor-control functions were required. Numerous successful applications have been made but practically all have been to problems extremely difficult if not impossible to solve by more conventional means.

However the new system described by the authors holds promise for obtaining with reasonable economy the advantages of adjustable speed motor operation where only alternating current is available. Thus it opens to the electronic control the field of applications in which the problem is merely to obtain adjustment of motor speed, rather than to obtain some special and more or less automatic control.

The system provides not only a source of direct current for operation and control of the motor by the conventional field rheostat method, but also an adjustable armature voltage. The wide speed range thus afforded makes it applicable to drives requiring a wider range than the conventional three-to-one or four-to-one adjustable-speed d-c motor. I believe this will make the system quite useful in certain machine tool applications, where greatly reduced speeds are sometimes needed.

For machine-tool application, the system provides one distinct advantage over the use of a motor generator set and exciter. This is that the equipment can be built up into a small cabinet which can be mounted directly on or in the machine in the same manner that magnetic controllers are now mounted. This is quite important in view of the decided trend toward making machine tools completely self-contained so that they may be readily moved for new production setups. Against this advantage, of course, is the fact that user must consider the cost of occasional tube replacements.

The armature current-motor-speed curves in the authors' figure 11 show a regulation at reduced speed which may be excessive for some applications. I do not believe that the slope of the main part of the curves will be excessive for most applications but the large increase in speed at very light loads may be objectionable. Individual applications would have to be studied to determine the suitability of the system in this respect. As the authors point out, the regulation may be improved by various compounding methods but of course this will complicate the system to some extent and one of the big economic advantages of the system is its inherent simplicity.

One other disadvantage, inherent to the simple rectifier systems, is that regenerative braking cannot be obtained without a very substantial increase in the cost and complexity of the equipment. For some applications only rapid braking is required and in such cases dynamic braking can be obtained by addition of suitable braking resistor and magnetic control. However, other applications require rapid deceleration to a reduced operating speed and the method of obtaining this operation automatically is more complex.

Although it is true that the system as described may be used to start the motor from rest without additional magnetic control, I believe that there may be some objection to this arrangement, particularly on machine tools in the high production industries. It would be difficult to educate the operators to accelerate the motor at a proper rate by turning a control knob when they have already been educated to push a button and obtain acceleration at the proper rate automatically.

In general, though, this new system is a distinct forward step and I believe numerous applications for it will be found.

C. H. Willis: The authors appreciate the interest shown in their paper by those giving discussions. It is evident from this wide interest that electronic devices may find a wide field of application in motor control. It is to be hoped that this field will develop rapidly.

In some of the discussions there appears to be a divergence of opinion as to the rating of the control equipment, where a rectifier and d-c motor are used to control the speed of a wound-rotor induction motor. Since this equipment is required to carry a maximum current under one condition of operation and also must produce a maximum voltage under some other condition, the authors believe that the proper rating is the product of the maximum current and voltage. While the control equipment may not operate at this rated load it must be capable of so operating and this rating gives the most accurate and conservative estimate of the apparatus.

Discussions

of AIEE Technical Papers Published Before Discussions Were Available

ON THIS and the following three pages appear discussions submitted for publication, and approved by the technical committees, on previously published papers presented at the AIEE winter convention, New York, N. Y., January 24–28, 1938. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

The PCC Street Car

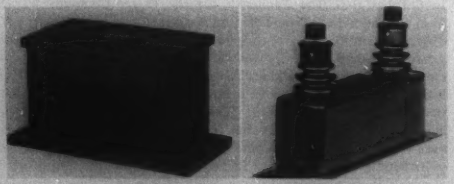
Discussion of a paper by C. F. Hirshfeld published on pages 61–6, of this volume (February section) and presented for oral discussion at the modern electric vehicles session of the winter convention, New York, N. Y., January 24, 1938.

E. J. Allen (General Electric Company, Pittsfield, Mass.): The author is to be commended for his description of the salient features of the modern Presidents' Conference Committee street cars, over 500 of which have been in operation during the past three years. Low operating cost and low maintenance expense to the transit company is obtained through applied research and careful design, yet securing modern appearance, speed consistent with good riding quality, good illumination, and ventilation.

The PCC street car, like its earlier predecessors, derives its motive power from overhead trolley lines, which are very frequently exposed to lightning, even in urban areas. Consistent with the objectives of low first cost, and low maintenance expense in general design of the PCC car, a d-c capacitor-type lightning arrester is installed in one of the compartments. To meet the demand for a d-c lightning arrester, which does not require maintenance and one that is unaffected by winter and summer temperatures, the d-c capacitor type arrester has been made possible only through successful research in dielectrics during the past few years.

Figure 1*a* shows a type of 750-volt four-microfarad d-c capacitor arrester which has been used on PCC cars. Another d-c capacitor-type arrester having the same electrical characteristics, but enclosed in a drawn steel housing, is shown in figure 1*b*.

This arrester is directly connected between positive trolley and car frame, and depends entirely upon the effect of a large amount of capacitance for its impulse protective characteristics. While the protective voltage maintained by the capacitor-type arrester depends on the wave shape and amplitude of the impulses applied on the trolley circuit, this protective level is only 3,000–4,000 volts crest for typical applied waves on trolleys supported by cross spans on steel or guyed wood poles. Moreover, the sloping of applied impulse wave front accomplished by the capacitor-type arrester is essential in order to reduce the turn-to-turn impulse stresses in the motors and car equipment.



(a) (b)

Figure 1. Typical d-c capacitor-type lightning arresters for 600-volt d-c service

The protective characteristics afforded by d-c capacitor arresters as shown by calculation and tests are rapidly being substantiated in service by the virtual lack of lightning failures reported on PCC car equipments.

W. I. Rodgers, Jr. (nonmember, Brooklyn and Queens Transit Corporation, Brooklyn, N. Y.): In Brooklyn, the Presidents' Conference Committee car was first introduced to the riding public. The 100 new cars replaced old equipment on four lines starting October 1, 1936. New schedules were written, headways reduced, and an improved service resulted. Rider endorsement followed quickly and the mails brought hundreds of appreciative comments.

To date, the cars have operated over five million miles. Comparing this with average mileages for older equipment we find that the new cars have traversed one-third more mileage over equal periods. As these cars are able to do more work per day, it follows that operation costs are lowered.

Much of the electrical and the mechanical equipment of the cars had been tested in Brooklyn on the widely known "million dollar" experimental car. Many more improvements were selected for the production cars. Fundamentals had been well established by the PCC research group. It remained for actual service operations on a wide scale to prove the equipment. The early experiences in Brooklyn with the first production cars from the factory quickly brought out the necessity for changes of slight importance in themselves but highly desirable for maintenance reasons. Both construction and engineering detail reflected the careful planning and long research to provide a modern vehicle that could be priced attractively to operating companies.

In the desire to build such a vehicle to these standards, no sacrifice of sturdy, dependable equipment and accessories was permitted. Thus, our operating difficulties have been minor and have not in any way interfered with smooth, successful performance during the year.

Our maintenance costs have not yet reached their level because of the changes and improvements applied after the delivery of the cars. It is confidently expected that costs will shortly match the system average and ultimately be less than the costs of maintaining the conventional street car of former days.

Reduced track costs are anticipated by the use of the resilient wheels and much elimination of the hammer-blow pounding of steel wheels on the rail seems assured. All lateral movement and swing of the car body is well controlled by the rubber coned springs at the four corners of the trucks and the body swing links. These design factors should go far toward reducing destructive forces which cause excessive track maintenance.

Coupling Between Parallel Earth-Return Circuits Under D-C Transient Conditions

Discussion and author's closure of a paper by K. E. Gould published on pages 1159–64 of volume 56, 1937, AIEE TRANSACTIONS (September 1937 issue of ELECTRICAL ENGINEERING) and presented for oral discussion at the communications session of the winter convention, New York, N. Y., January 24–28, 1938.

G. Wascheck (Bell Telephone Laboratories, Inc., New York, N. Y.): Experimental measurements made in connection with the d-c transient induction tests presented in Mr. Gould's paper afforded opportunities for studying certain aspects of the problem of determining local earth resistivities and structures—which problem is an important one in predicting the a-c coupling between earth-return circuits. If the earth were uniform, such resistivity would be independent of separation or frequency. If the earth were not uniform but varied as some function of the depth, the resistivity would vary

with frequency because of the lesser penetration of the current to the lower depths and the increased concentration closer to the surface as the frequency is increased—a phenomenon closely allied to that of skin effect with which we are all familiar as applied to metallic conductors. This is also reflected in a change of the in-phase and quadrature components of the coupling from that of a uniform earth structure. Thus, a series of tests over a large frequency range would show variations in the resistivity indicated at the surface which would be a function of the depth, and from which interpretations of the structure may be made—provided, of course, that such variations are roughly in a horizontal plane and not too deeply submerged for the frequencies employed. The resistivity indicated at the lower frequencies and hence influenced by the resistivity of the lower depths is not necessarily the actual resistivity at the lower levels but rather a composite of the entire cross section of the area through which the current is distributed. Therefore, whereas the trend will qualitatively indicate resistivity variations, comparisons with theoretical calculations for simple structures are required in order to determine the nearest equivalent structure.

For example, from the Jennings, La., test results, a curve of resistivity based on the magnitude of the mutual impedance (differing slightly from the curves in figure 13 of the paper, which are based upon the reactive component of the mutual impedance) was plotted against frequency, and indicated variations as follows: a resistivity of about 15 meter-ohms at 20 cycles, increasing to over 30 meter-ohms at 100 cycles, and then decreasing eventually to about ten meter-ohms at 3,200 cycles. Calculations show that this trend may be explained on the basis of a horizontally stratified earth, and geological studies substantiate the existence of such a structure in this region, which is in the so-called delta country around the mouth of the Mississippi River. This area has been built up by the deposition of silt over a great number of years and is probably quite uniform in a horizontal plane. In addition, experimental results were available, of resistivity measurements made in a 2,000-foot oil well a few miles distant, which indicated a surface layer over a hundred feet thick of rather low resistivity, a second layer below this several hundred feet thick with a resistivity about three to four times as high, and below this a gradual change to a very low resistivity, which low value is no doubt due to the salt water which underlies this territory.

A simpler method for determining earth resistivity and structure, requiring less time and apparatus than the a-c tests and easily analyzed when the structure is not too complex, is that employing direct current. Such tests were also made at this site and comparisons with the above results indicated a close correlation with the general resistivity trend and structure.

The d-c procedure, which has been used for some time in detecting variations in the earth's structure, particularly in geophysical prospecting work, consists in applying direct current (periodically reversed through a commutator to reduce polarization and stray voltage effects) to a pair of ground electrodes, called the current electrodes, and measuring the potential between two intermediate electrodes, called potential electrodes. This determines the mutual resistance between the two circuits from which, with the known geometrical arrangement of electrodes, the apparent uniform earth resistivity may be determined directly by a simple formula. To determine possible variations of resistivity with depth, use is made of the fact that the direct current penetration into the earth becomes progressively greater as the spacing between the electrodes is increased. When these variations with spacing assume certain definite trends, calculation and tests on small models have shown that a fairly reliable interpretation of the structure may be made. The tests at Jennings, which were made with current electrode spacings from a few feet up to nearly 10,000 feet indicated a resistivity of little over ten meter-ohms at the closer spacings which increased to 35 meter-ohms at the intermediate spacings and then dropped off rapidly at the last measured point, indicating about six meter-ohms with the trend still downward. These results agree essentially with the oil well data and with the a-c results, where a continuation of the measurements below 20 cycles quite likely would have shown a progressive drop in resistivity to the d-c value for a very wide spacing of electrodes.

Thus, provided the coupling characteristics for the resultant structure are known, or an equivalent earth resistivity can be substituted for it at a given frequency, results from d-c exploration tests enable a close estimate to be made of the a-c coupling. Tests in many places have indicated that where the structure is not too complex, an equivalent uniform or a two-layer stratified structure may be postulated from d-c exploration data, and for these cases the variations of coupling with separation can readily be calculated. More complex structures may often be reduced to a simpler structure, though invariably in heterogeneous territory, irregularities in a horizontal direction are also present. These introduce difficulties in assigning an average resistivity, especially for a long circuit, when only exploratory or sampling measurements are made. This is true when measurements are made either by the a-c or d-c method and a larger portion of the territory must be explored. However, where sampling methods are deemed satisfactory, the d-c procedure provides a useful method for predicting a-c coupling between earth-return circuits.

A New Single-Channel Carrier Telephone System

Discussion and authors' closure of a paper by H. J. Fisher, M. L. Almquist, and R. H. Mills published on pages 25–33 of this volume (January section) and presented for oral discussion at the communications session the winter convention, New York, N. Y., January 24–28, 1938.

Glen Ireland (American Telephone and Telegraph Company, New York, N. Y.): The members of the Institute may be interested in some brief comments regarding the application of the type-*H* system in the Bell System plant.

About 35 type-*H* systems have been placed in commercial service and engineering has been completed on a great many more. Some of the systems are being applied for distances as short as 25 miles, others are being used for distances up to 160 miles. In the engineering of these systems, the small size of the *H* terminals is being found to be of considerable advantage particularly in offices where floor space is at a premium. In the case of one office it was possible to defer the enlargement or rearrangement of the toll terminal room and at the same time take care of the toll circuit growth by removing three low bays containing three type-*D* terminals and in their place installing two low bays containing 4 type-H terminals. The type-D terminals are to be reinstalled elsewhere where floor space is not a controlling factor.

Experience with the *H* systems already in service although limited, has been very satisfactory. The circuits are providing good quality, are very quiet and relatively stable. The systems are simple and easy to maintain, relatively few routine maintenance tests being required. In particular the use of varistors as the modulating and demodulating elements is helpful since it results in greater freedom from carrier leak and avoids the tests and adjustments of carrier leak required rather frequently in the case of previous types of systems employing vacuum tubes.

E. E. George (Tennessee Electric Power Company, Chattanooga): In October 1937 The Tennessee Electric Power Company leased from Southern Bell Telephone and Telegraph Company a type-*H* carrier system for use over the power company owned telephone line between Nashville and Chattanooga. This carrier system has provided one of the finest talking channels that we have ever used. The quality and volume are above the levels on the best toll circuits and the noise level is almost zero. This latter point is particularly remarkable in view of the fact that the power company telephone line over which this channel operates is "a hot telephone line" for most of its length. This telephone line consists of 165 miles of open wire of which 85 miles are on the same right-of-way as 110-kv transmission line. The line has several way stations with the usual drainage coils and insulating transformers. A portion of this circuit constitutes the side leg of a phantom with mid-tapped insulating trans-

formers used for phantom coils. At one end there is a few hundred feet of entrance cable.

During the installation of the type-*H* carrier channel it was assumed that the two insulating transformers in the main line would have to be by-passed with high voltage condensers but it was found possible to operate without by-passes provided the ringing gain was increased sufficiently. By-passing insulating phantom transformers was found to make the phantom circuit useless due to the effect of the condensers in transmitting longitudinal noise frequencies. The circuit has been operating satisfactorily several months with one insulating transformer by-passed and one without by-pass.

The line has several way stations and the only changes made at these stations were to install small low pass filters ahead of the subsets on the station side of the connecting key or cord circuit. These filters are thus normally kept off of the line.

At present the power supply for the carrier terminals is derived from 115 volts a-c although 130 volts d-c is available near by. For communication under emergency conditions such as dispatching, it would be highly desirable if the equipment could be modified to work off 130 volts d-c with no intermediate taps and no separate 24-volt battery. When the installation was first made some of the way station filters were omitted temporarily. Although the use of the voice channel created noise on the carrier channel and vice versa, the modulation was apparently inverted and the crosstalk was unintelligible. For this reason filters have been omitted at the patrol booth stations which are seldom used.

To power engineers familiar with the usual weaknesses of copper oxide rectifiers in the matter of heating, aging, overloading, etc., it seems remarkable that rectifiers have been found to be satisfactory as modulators and detectors in a high grade communication circuit. Elsewhere it has been stated that in some respects the copper oxide rectifier is superior to the vacuum tube for such purposes and it would be interesting to hear the authors of this paper discuss this factor in a little more detail. As noted the space requirements of the new "H" terminal are small, and its low cost makes it very attractive to power companies and others even on relatively short telephone lines. A type "H" carrier terminal has recently been installed by a neighboring company over a 20 mile telephone circuit on power line right-of-way where rectifier noise made the voice frequency circuit unusable. The channel has been so satisfactory that a second one is being installed.

J. E. Smith (nonmember; RCA Communications, Inc., New York, N. Y.): During his presentation Mr. Almquist stated that ten copper-oxide disks were series connected in each branch of the modulator bridge arm. Was the multiple-disk varistor used to permit high-signal-level inputs, and, if so, what was the maximum signal level?

M. L. Almquist: Mr. George suggested that some further discussion of the advantages of copper-oxide varistors over vacuum tubes as modulators and demodulators would be of interest. The principal advantages are better balance, greater stability, lower cost, smaller size, and reduced power consumption. The modulator circuit in the type-*H* system consists of a copper-oxide varistor and a single tube amplifier. To accomplish the same result with vacuum tubes would require the use of three tubes, two tubes operating as a single-balanced modulator and one tube operating as an amplifier. In order to obtain a good balance in the vacuum-tube modulator, which is necessary in order to reduce carrier leak and unwanted modulation products, it is frequently necessary to select pairs of tubes whose characteristics closely match each other. The balance will change as the tubes age and will also vary with changes in the power supply voltages. The copper-oxide varistor as manufactured has a balance which is better than can be obtained with vacuum tubes and this balance is maintained over long periods of time, thus avoiding the periodic rebalancing which is required when vacuum tubes are employed. Furthermore, with a double-balanced modulator such as is used in the type-*H* system, the input frequency does not appear in the output and this simplifies the filter requirements.

In reply to Mr. Smith's question, the primary purpose of using a multiple disk varistor is that it affords an economical way of obtaining units which are uniform in their performance, well balanced, and stable with time. The load-carrying capacity is determined largely by the amount of carrier which is applied; in order to obtain good performance, the carrier voltage across each disk must be larger than the speech voltage peaks at the same point. In this system, the modulator operates at a level which is four decibels below and the demodulator at a level 13 decibels below that at the toll switchboard. The power which can be carried by the modulator without noticeable distortion is of the order of five to ten milliwatts.

A System of Electric Remote-Control Accounting

Discussion and author's closure of a paper by L. F. Woodruff published on pages 78–87 of this volume (February section), and presented for oral discussion at the communications session of the winter convention, New York, N. Y., January 24–28, 1938.

E. R. C. Coe (The National Cash Register Company, Dayton, Ohio): I should like to ask Mr. Woodruff how a customer would identify himself in the event of a lost "charge token." It would seem that permission to set up the account number by hand at the sales counter somewhat destroys the safety of the system.

A. B. Smith (Associated Electric Laboratories, Inc., Chicago, Ill.): This paper deals with the general structure and operation of a system of accounting which is a combination of mechanical and electrical devices. In harmony with the scope of the paper, the author does not treat of these devices.

The business man of today has been fully acquainted with complicated mechanical devices, and he has learned to depend upon them to a very large extent. Beginning with the typewriter, he has been led on to the use of simple adding machines, and from them to the more capable machines like the Comptometer and the several calculating machines. As to their essential functions they are purely mechanical, and though he does not know what is in them, the business man has learned to rely on them. His confidence is justified.

In the accounting system described in this paper, there is the added element of many electrical circuits and devices. The business man may rightly ask, "To what extent are these electrical devices reliable, and what will their failure do to me?"

As most electrical engineers know, for many years the railroads have been using block systems for the safety and expedition of trains. They have made increasing use of interlocking plants to control switches, derails, and signals intersections. In all of these electrical appliances, the circuits are so designed that any failure will result in such a signal aspect as to give a more restrictive indication. Each failure is on the side of safety.

In the case of this electrical accounting, it is of interest to the prospective user to know if similar safeguards exist. He will also like to know the frequency with which electrical faults actually occur, or may be expected to occur. Experience with automatic switching of telephone lines has revealed the high degree of accuracy and dependability which relays and magnets can furnish.

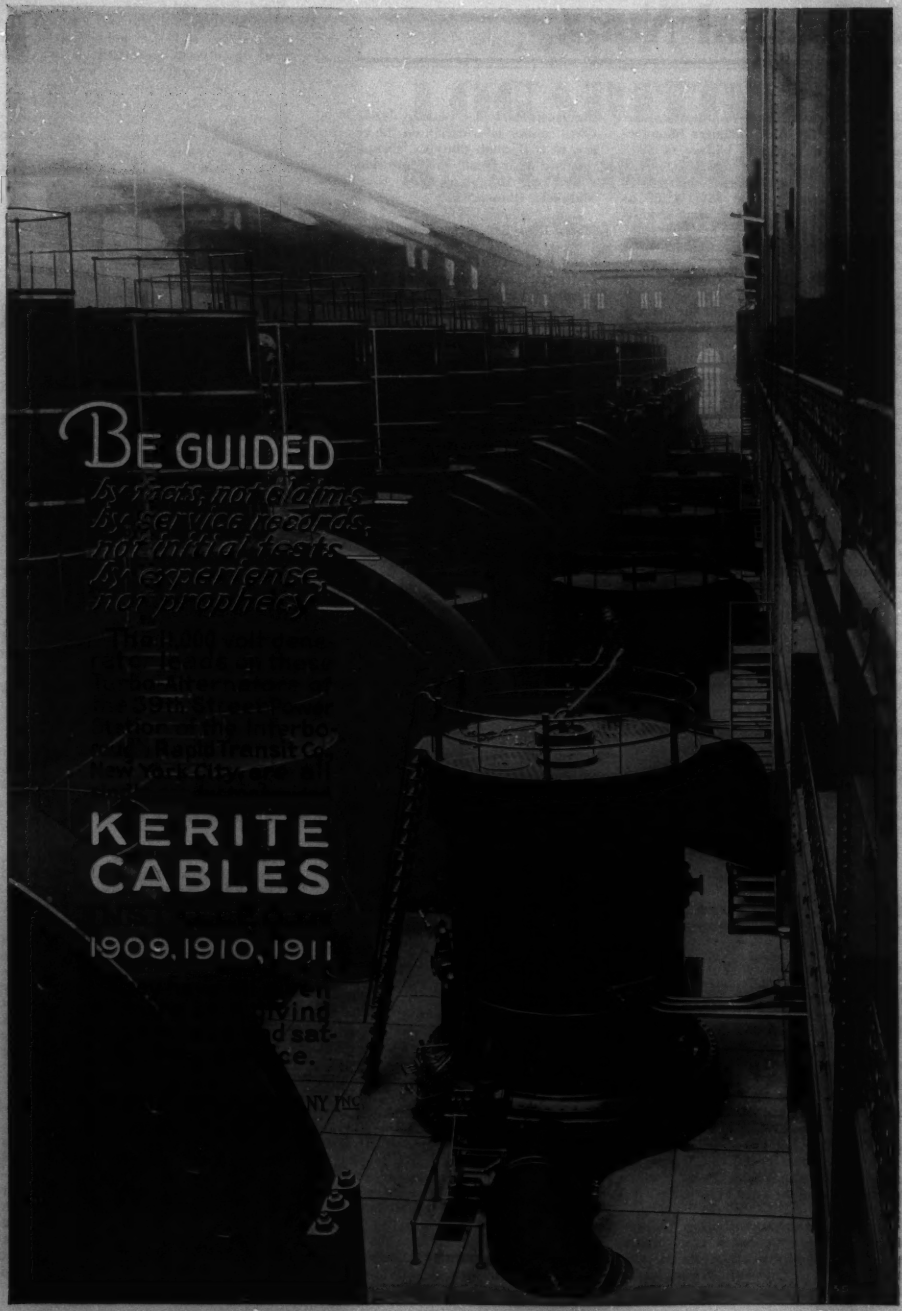
L. F. Woodruff: Doctor Smith's remarks touch on a most pertinent aspect of the system, and one which has been of foremost importance in the development of the individual machines and circuits. This is primarily the elimination of possible error in transmission, and secondarily, the assurance of continuity of operation.

Twin contacts in parallel are used on all circuits. Contacts through the holes in the tags at the transmitter are made at two points. The coding of the numbers to be transmitted has been selected so that just two holes comprise the code for each digit. A contact failure, or an extra hole, will result not in an erroneous trans-

mission, but the control circuits have been designed so that this event would cause a stoppage of transmission. The record would be incomplete, and the price tag would not be stamped. The transmitter would remain locked, and would have to be released by a special key. The record would have to be transmitted over again. If the transmitter were actually defective it would of course have to be replaced.

Mr. Coe has asked how a customer would identify himself in the event of a lost charge token. I agree with his point that setting up the number by hand at the sales counter would somewhat reduce the safety of the system, and we do not recommend that method. We advocate providing at a service station on each floor a place where the customer, upon proper identification, can be provided with a temporary token, good for that day only. A duplicate of this token would be filed for use in making correction in event an error was made in punching.

There are other possibilities for handling this problem, and the final choice must rest with the store management.


BE GUIDED
by facts, not claims—
by service records,
not initial tests—
by experience,
not prophecy—
KERITE
CABLES
1909, 1910, 1911

Industrial Notes

Allis-Chalmers Billings.—For the first quarter this year the Allis-Chalmers Manufacturing Company reports billings of $20,310,099 compared to $17,788,395 for the same months in 1937. Orders booked for the first quarter totalled $19,314,557 as against $24,205,565 for the same months last year. Unfilled orders on March 31 totalled $20,248,025 as against $20,235,507 a year ago.

Radio Equipment for Air Ways.—The first of 44 radio range stations built for the Department of Commerce by the Westinghouse Electric & Mfg. Co. will be installed at Allentown, Pa. The installations all will be made on regular established air routes and will be located in some 20 states. In addition to the complete equipment and installation of the 44 radio range stations, Westinghouse is supplying 50 single transmitter equipments which are to replace present obsolete units. The radio range station equipment supplied for each installation includes everything except the antenna towers and the main building to house the equipment. The principal items of the equipment are the transmitter unit, the coupling unit and the antenna tuning units. The transmitter unit transmits both voice signals and radio range signals. These can be transmitted simultaneously which is not true of the system in general use at the present time. Now it is necessary to interrupt the range signals for the period of time that the weather broadcast is being transmitted.

General Cable Moves Chicago Office.—The General Cable Corporation has moved its Chicago office from 20 North Wacker Drive to 111 North Canal St. The consolidation of office and warehouse provides complete facilities for the continuation of prompt service.

Trade Literature

Voltage Regulators.—Bulletin 1185A, 12 pp. Describes recent changes and developments in type BFR automatic branch feeder voltage regulators. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Fuse Links.—Bulletin 533A. Describes fuse links for plug type cutouts and cartridge type secondary fuses. W. N. Matthews Corporation, St. Louis, Mo.

Line Protection Equipment.—Cat. Sec. 5, 4 pp. Describes motor operated, automatic service restorers. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Network Transformers.—Bulletin B2134, 20 pp. Describes application, construction and design of network transformers and other network equipment. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Pintype Insulators.—Bulletin 643-H, 6 pp. Gives catalog information on the complete line of O-B small pintypes, including the standard designs and the multi-ridge units known as Kingpins. Ohio Brass Co., Mansfield, Ohio.

Metal Clad Switchgear.—Bulletin 1145B, 16 pp. Describes horizontal, drawout, metal clad circuit breaker equipment for power stations, substations and general industrial purposes. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Reconditioning Equipment.—Bulletin GEA-2571B, 20 pp., "Reconditioning Flooded Electric Equipment." A detailed exposition of recommended methods for reconditioning water-immersed electrical apparatus. General Electric Co., Schenectady, N. Y.

Pyrometers—Bulletin 488, 12 pp. Describes millivoltmeter pyrometers. Types include: indicator controllers with enclosed mercury contacts or solid metal-to-metal contacts; single point indicators, and multiple-point indicators with rotary switch. The Bristol Co., Waterbury, Conn.

Wiring System.—Bulletin, 12 pp., "How to Mobilize Lighting and Power Outlets in Industrial Plants with Trol-E-Duct." Describes a flexible wiring system providing movable outlets. Applications in factory departments are illustrated. Bull Dog Electric Products Co., 7610 Jos. Campau Ave., Detroit, Mich.

Tap Switches.—Bulletin 381. Describes new developments in instrument type tap switches. This new line of switches covers both r.f. and low frequency applications. Standard units are available up to 60 amperes. All switches may be supplied with Mycalex insulation for use on the higher radio frequencies. Tech Laboratories, 7 Lincoln St., Jersey City, N. J.

Insulators.—Descrip. Data 39-180, 8 pp. Describes several types of high voltage pin type insulators including multipart design for average conditions, one piece high voltage insulators and bullet-proof types. Contains diagrams showing dimensions and construction; tables include wet and dry flashover, arcing distance, mechanical strength, etc. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Flexible Shafts—Bulletin 38, 28 pp. Describes flexible shafts for remote controls, applicable in operating from an accessible point, switches, valves and other electrical and mechanical controls located in remote or inaccessible positions. Shafts can be applied for either manual or automatic operation of controls; also, for operating any element requiring rotation or push-pull movement or both, with the controlled element close to or at a distance from the point of control; and for operating indicators of all kinds. Industrial Div., S. S. White Dental Mfg. Co., 10 East 40th St., New York.

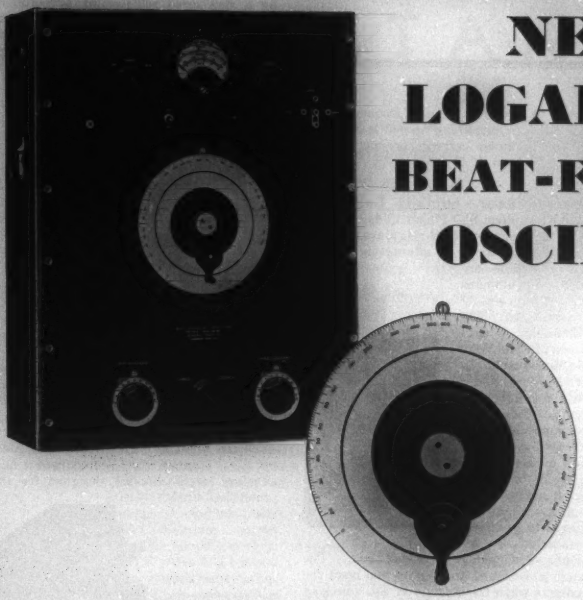
Wood Pipes and Tanks.—Catalog "Wood Pipe Handbook," 275 pp., contains 150 illustrations. The subject matter ranges from an authoritative section on hydraulics to a description of the manufacture and application of wood pipe. A section is included in which problems encountered by engineers are solved both scientifically and through the use of flow tables prepared especially for this pocket size handbook. "Wood Tank Catalog" No. 37 describes tank installations of a wide variety. It shows how tanks and their foundations are designed and erected. Illustrations clarify many features of tank construction not usually published. National Tank & Pipe Co., Portland, Ore.

Highway Lighting.—Bulletin GEA-1097B, 8 pp. Illustrates and describes luminaires and accessory equipment, including discussion of arrangement and mounting height of units. The booklet further recognizes the significance of the different road surfaces, colors, and widths. The different G-E luminaires have various lighting characteristics, and sample charts show the performance of these luminaires in relation to unit height and street width. Line diagrams illustrate the construction of recommended mast arms and steel poles. Tables indicate prices of the different parts listed in the bulletin. General Electric Co., Schenectady, N. Y.

Instrument Transformers.—Bulletin B2138, 12 pp. Describes new instrument transformers providing reliable metering at low cost. The features covered are coordinated insulation, new wide-range accuracy on over-currents through type FW current transformers, potential transformers giving double protection against impulse voltage, quick-change construction of base and terminals to simplify changing current transformers to meet varying loads, and meter box which houses two FW current transformers with watthour meter and socket on cover. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Subway Oil Disconnects.—Bulletin 364, 8 pp. Describes type RA primary and type ARA secondary subway oil disconnects. The latter is a new addition to the G & W line of subway sectionalizing equipment. These boxes use floating contact rocker arm disconnecting links, gang operated by means of a handle on the outside of the box. The cables are sealed as they enter the box by means of individual porcelain insulated cable heads. The boxes provide a quick and easy means of switching secondary circuits and for isolating or interconnecting sections of cables. G & W Electric Specialty Co., 7780 Dante Ave., Chicago, Ill.

Line Material.—Bulletin 640-H, 36 pp., "O-B Materials for Distribution and Farm Lines." Describes pintype, suspension and porcelain insulators used for primary distribution circuits and farm lines; insulator fittings, etc., drawings are included which are typical of construction generally used to meet the demand for reliable low cost lines in rural territory; conductor tables; and data for designing such lines. Ohio Brass Co., Mansfield, Ohio.



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Type 713-B
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THE NEW Type 713-B Beat-Frequency Oscillator has a frequency range of 10 to 40,000 cycles. The extended upper limit is supplied for both general-purpose laboratory measurements and for the supersonic field.

This oscillator is equipped with a direct-reading logarithmic frequency scale calibrated from 20 to 20,000 cycles. The dial upon which this scale is engraved may be equipped with a gear to drive a recorder using logarithmic or semi-logarithmic paper.

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1. WIDE FREQUENCY RANGE.....10 to 40,000 cycles
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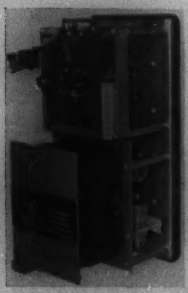
MANUFACTURERS of RADIO and ELECTRICAL LABORATORY APPARATUS

New Products

Voltmeters.—Portable, multi-range, model 433, a-c voltmeters with improved temperature compensation are now being offered by the Weston Electrical Instrument Corporation, Newark, N. J. The improvement will

be of particular benefit in field test work by public utilities, where temperatures ranging from −20° to 120° F may be encountered. Instruments of the double range type (300/150 volts) and the triple range type (600/300/150 volts) are available with the improved compensation which holds temperature errors to 1% for 60°C (140°F) on both the 150-volt and 300-volt ranges and to 1% for 240°C (464°F) on the 600-volt range. Due to the special internal connections on these improved instruments, switches are used for range changing purposes, the switch for the double-range instrument being a double-pole, double-throw toggle switch and that for the triple-range type a double-pole, 3-position rotary switch.

Relay.—A new harmonic restraint current relay for use in bus differential protection has been announced by the General Electric Co. The new relay employs a principle of harmonic restraint to prevent it from operating because of current transformer transient unbalances. An operating element and a restraining element give this type HDC relay an identical construction to that of the fault detector of carrier - current protective apparatus. The operating circuit is tuned to pass fundamental line frequency and the restraining circuit is tuned to block fundamental frequency. As a result, the restraining current is composed of any harmonic currents present and the d-c component, if any.

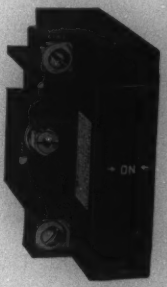


Overload Relay.—Struthers Dunn, Inc., 129 N. Juniper St., Philadelphia, Pa., announces a new overload relay available for use on either direct or alternating current. The contacts are rated 30 amperes at 110 volts a-c, 20 amperes at 220 volts a-c, 6 amperes at 110 volts d-c, and 3 amperes at 230 volts d-c on non-inductive loads. This relay is somewhat similar to the company's line of mechanical latch-in electrical reset relays. The contacts can be arranged to be closed manually or by means of a voltage operated coil. The latch is adjusted to pick up and open the contacts when the current in the overload coil reaches the proper value. This setting is adjustable by means of the knurled nut on the top of the relay over a range of 2 to 1.

Breakers House Metering Equipment.—A novel feature of 196–230 kv oil circuit breakers built by the Pacific Electric Manufacturing Company for installation by the City of Seattle (Wash.) at its Diablo hydroelectric generating station is the use of 12 bushing type current transformers arranged to serve the requirements of both metering and protective relays. Mounted two on each bushing, nine 1200/5 serve the relays, and three of the same ratio equipped with reactors serve the metering requirements. These breakers are reported to have been the first in which two bushing type current transformers per pole were used.

Running Time Meter.—R. W. Cramer & Co., Inc., 67 Irving Pl., New York City, announces a new running time meter which automatically registers the operating time of the circuit, apparatus or system to which it is connected. The meter, driven by a slow-speed self-starting synchronous motor, is made in two types—for registering total hours and total minutes. The device has a wide range of applications, including the recording of actual operating time of processing and production machines, x-ray and diathermy apparatus, blowers, welders, etc., and also for time study.

Auxiliary Breaker.—The Heinemann Electric Co., Trenton, N. J., announces a new auxiliary circuit breaker designed for the protection of fractional horsepower motors up to one horsepower and in ratings from 250 milliamperes to 35 amperes. A magnetic time delay unit takes care of harmless overloads while it opens instantaneously on heavy overloads and short circuits. Magnetic blowout contacts will withstand short circuits and reduce arcing to a minimum. All moving parts except handle are enclosed in a Bakelite case.

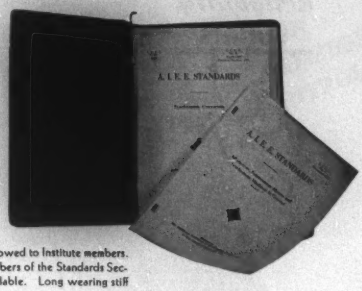


Looped Strain Clamp.—To simplify the job of dead-ending small conductors, the Ohio Brass Co., Mansfield, Ohio, has added a loop under the nose of its small Hi-Lite

strain clamp, making it possible to attach the "blocks" for securing proper conductor tension directly in the clamp. When the tail block is hooked in the new loop and the conductor is brought to tension, the entire dead-end assembly assumes a position that is practically a continuation of the conductor. In addition to simplifying the procedure of dead-ending, the loop permits more accurate sagging and makes hot line work easier and safer.

A.I.E.E. STANDARDS

THE Standards of the American Institute of Electrical Engineers now comprise forty-seven sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.



The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members. Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available. Long wearing stiff covers, resembling leather, lettered in gold. Price $1.75 net.

(Figures in Parentheses Give Dates of Latest Editions)

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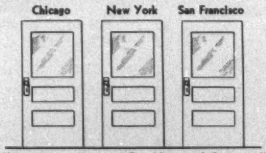

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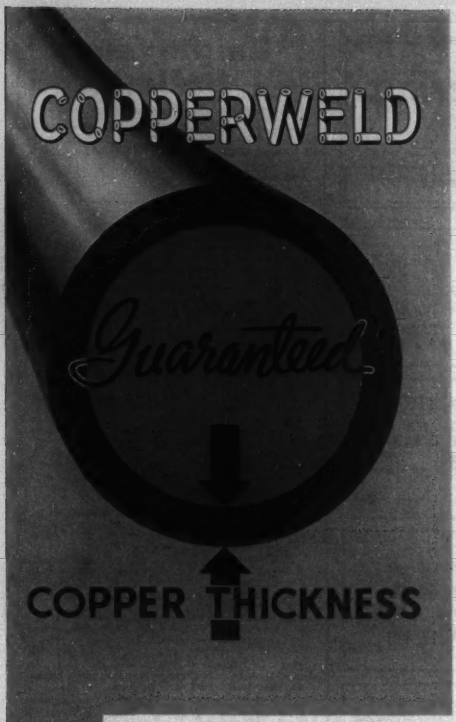

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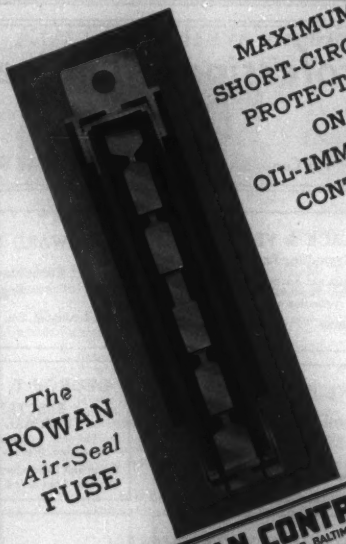

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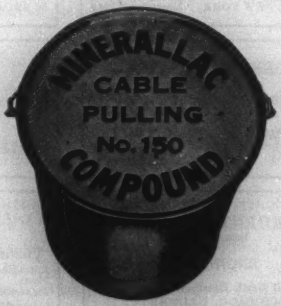

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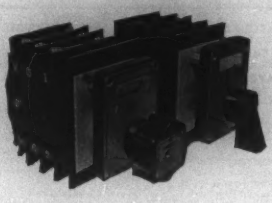

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Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Magnet
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Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
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Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Tree Wire
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
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Copperweld Steel Co., Glassport, Pa.
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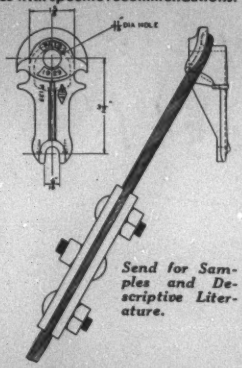

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